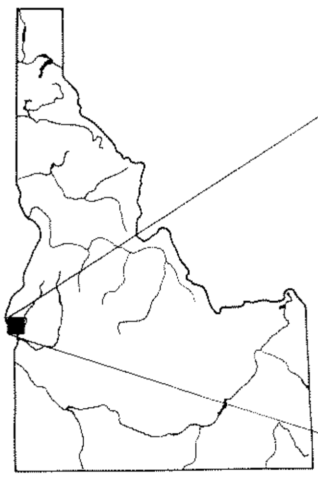
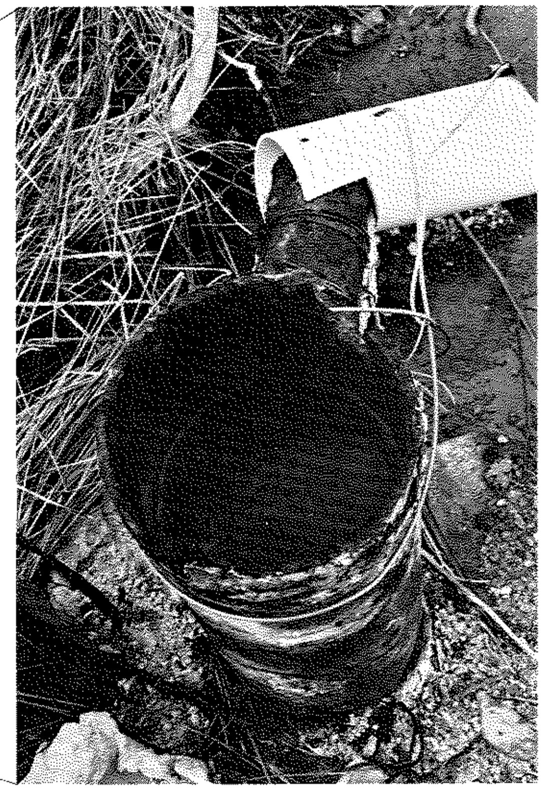
GEOTHERMAL INVESTIGATIONS IN IDAHO

Part 12

STABLE ISOTOPIC EVALUATION OF THERMAL WATER OCCURRENCES IN THE WEISER AND LITTLE SALMON RIVER DRAINAGE BASINS AND ADJACENT AREAS, WEST-CENTRAL IDAHO, WITH ATTENDANT GRAVITY AND MAGNETIC DATA ON THE WEISER AREA

Thermal Well Near Weiser Hot Springs, Washington County, Idaho.





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Part 12

Stable Isotopic Evaluation of Thermal Water Occurrences in the Weiser and Little Salmon River Drainage Basins and Adjacent Areas, West-Central Idaho with Attendant Gravity and Magnetic Data on the Weiser Area

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TABLE OF CONTENTS

LIST OF TABLES

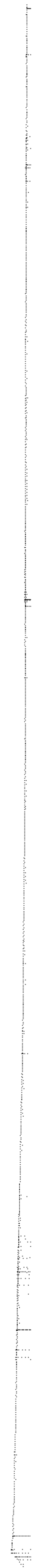
LIST OF FIGURES

ABSTRACT

Fifteen thermal springs, two thermal wells, and eight cold springs in the Weiser and Little Salmon river drainages were sampled for deuterium and oxygen-18 analysis during the fall of 1981. The straight-line fit of δD and $\delta^{18}O$ versus latitude and longitude observed in the data is what would be expected if the recharge areas for the thermal and non-thermal waters were in close proximity to their respective discharge points. The discrete values of δD and $\delta^{18}O$ for each thermal discharge suggest that none of the sampled thermal systems have common sources. The depleted deuterium and oxygen-18 contents of most thermal relative to non-thermal waters sampled suggests that the thermal waters might be Pleistocene age precipitation. The isotopic data suggest little or no evidence for mixing of thermal and non-thermal water for the sampled discharges. Thermal waters from Weiser, Crane Creek, Cove Creek, and White Licks hot springs show enrichment in oxygen-18 suggesting that these waters have been at elevated temperatures relative to other sampled thermal discharges in the area.

Gravity and magnetic data gathered by the Idaho State University Geology Department in the Weiser Hot Springs area suggest that southeastward plunging synclinal-anticlinal couples, which underlie the hot springs, are cut south of the springs by a northeast trending boundary fault. This fault terminates to the east at a northwesterly trending high-angle basin boundary fault near the hot springs. These faults appear to impede ground-water flow from the hot springs area towards the south and east. A fault west of the synclinal-anticlinal couples seems to act as a similar barrier to ground-water flow. These fault barriers may have "backed" water up the southerly plunging folds. Leakage through the fault barrier may explain the occurrence of thermal water in the West Weiser Flat area.

The high-angle fault east of the hot springs area is a possible source for the thermal water. The high-angle faults associated with a graben structure believed to exist near the western margin of the study area may also provide conduits for the movement of thermal water.



INTRODUCTION

PURPOSE AND SCOPE

This report represents another attempt to understand and evaluate the thermal water occurrences in the Weiser Hot Springs and adjacent areas to the north in west-central Idaho. See Figure 1 for location. The purpose of this report is to further examine and evaluate the geothermal potential of the Weiser Hot Springs and adjacent areas by obtaining more thermal-water chemistry data from existing springs and wells; obtaining pertinent geological, geophysical, and hydrological data from the literature; presenting the field-work data; describing the occurrence and chemical characteristics of the thermal waters; interpreting the existing and newly acquired data and relating it to the geothermal potential; developing the information necessary to formulate regulatory strategies if and when deep drilling in the area commences; and recommending areas of additional work where needed. The report consists of essentially two parts, a gravity and magnetic study of the Weiser Hot Springs area and a stable isotope study of the same area and adjacent areas to the north within the Weiser and Little Salmon River drainages.

The gravity and magnetic study included approximately 72 sq km (28 sq mi) of the Weiser portion of Washington County, an area marginal to the Snake River Plain immediately north of Weiser, Idaho. Both gravity and magnetic maps of this area have been prepared. This report attempts to interpret this geophysical data in terms of surface and subsurface geological conditions. It was anticipated that these surveys would supplement other studies and provide subsurface geologic information essential to the determination of a probable source for the hot waters. The type and location of major faulting in the area, the general structural and/or stratigraphic configuration of the area, and pertinent information concerning the nature and extent of the thermal resource are thus topics of major concern to be addressed, based on results of the surveys conducted.

In addition to gravity and magnetic surveys, a limited geochemical survey was conducted using the stable isotopes of hydrogen and oxygen in areas to the north and east of the Weiser Hot Springs area in order to obtain more information on thermal water sources. Shallow subsurface geologic and hydrologic data were obtained from existing well logs in the Weiser area to determine aquifer and shallow subsurface structure. Geologic mapping was taken from existing maps, augmented by field visits, to acquire more information on possible structures observed on the field maps and in the subsurface geologic and hydrologic data. Temperature gradients were obtained from existing unused drill holes.

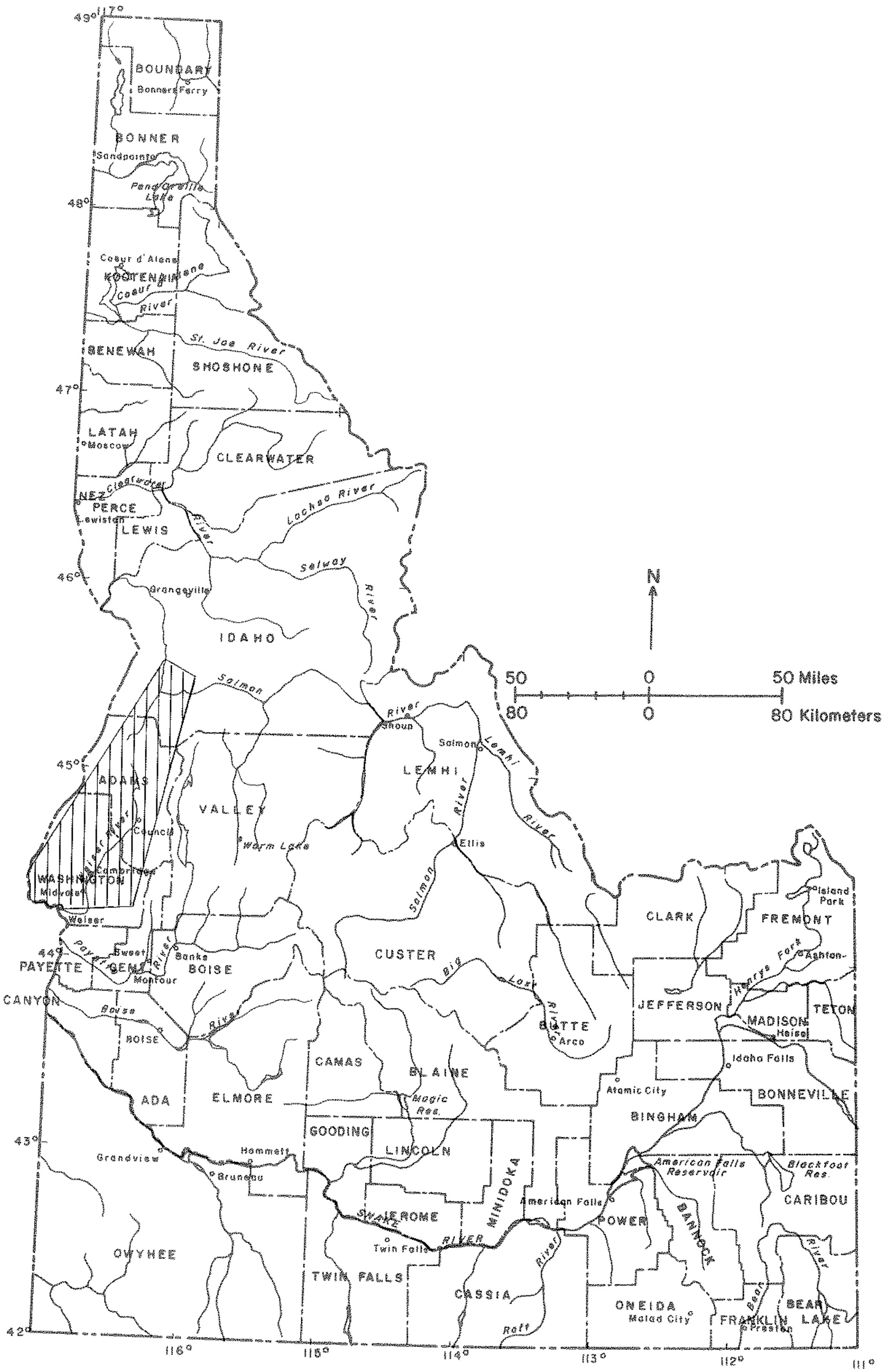


FIGURE 1. Index map of Idaho showing area covered by this report.

Limited funding prevented further geophysical work, such as shallow and deep resistivity surveys, which might give more definitive information about the deeper structure.

WELL- AND SPRING-NUMBERING SYSTEM

The numbering system used by the Idaho Department of Water Resources and the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and Meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. Quarter sections are lettered a, b, c, and d in counterclockwise order from the northeast quarter of each section (Figure 2). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 11N-6W-10cca1 is in the NE-SW-SW of Section 10, T11N, R6W, and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example 11N-6W-10acb1S.

USE OF METRIC UNITS

The metric or International System (SI) of units is used in this report to present water chemistry data. Concentrations of chemical substances dissolved in the water are given in milligrams per liter (mg/l) rather than in parts per million (ppm) as in some previous Water Information Bulletins. Numerical values for chemical concentrations are essentially equal, whether reported in mg/l or ppm, for the range of values reported in this report. Water temperatures are given in degrees Celsius (^{o}C). Conversion of ^{o}C to ^{o}F (degrees Fahrenheit) is based on the equation, $^{o}F = 1.8^{o}C + 32$. Figure 3 shows the relation between degrees Celsius and degrees Fahrenheit.

Linear measurements (inches, feet, yards, miles) are given in their corresponding metric units (millimeters, meters, kilometers). Weight and volume measurements are also given in their corresponding metric units. Table 1 gives conversion factors for these units. Area measurements are listed in both SI and English units except when referring to areas described by official rectangular subdivision of public lands.

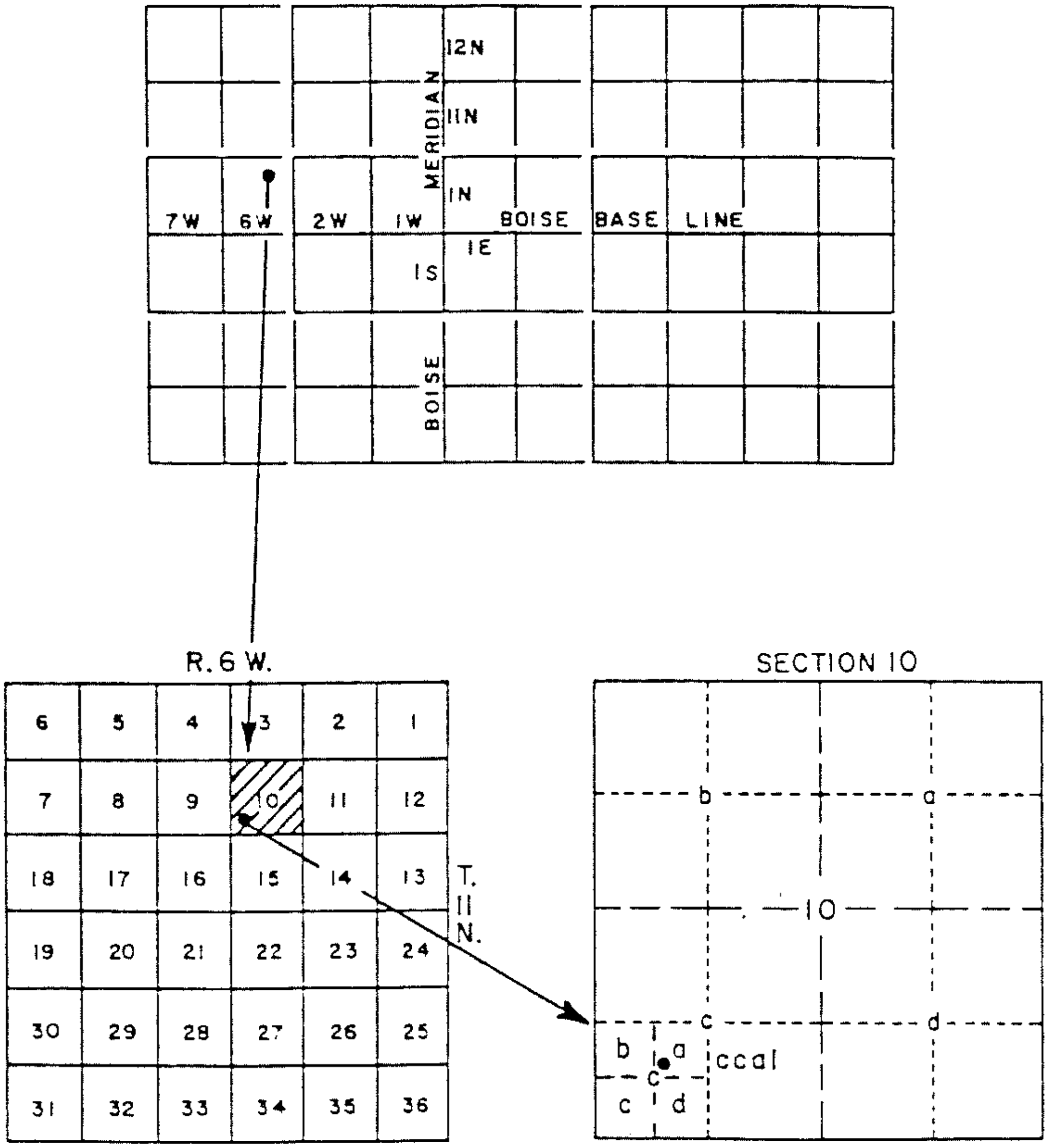


FIGURE 2. Diagram showing the well- and spring-numbering system. (Using well 11N-6W-10cca1.)

TABLE 1
CONVERSION FACTORS

To Convert from	To	Multiply by
	DISTANCE	
inches (in)	centimeters (cm)	2.540
feet (ft)	meters (m)	0.305
yards (yd)	meters (m)	0.914
miles (mi)	kilometers (km)	1.609
centimeters (cm)	inches (in)	0.394
meters (m)	feet (ft)	3.281
meters (m)	yards (yd)	1.094
kilometers (km)	miles (mi)	0.621
	AREA	
square miles (sq mi)	square kilometers (sq km)	2.589
sq kilometers (sq km)	square miles (sq mi)	0.386
	VOLUME - MASS	
gallons (gal)	liters (l)	3.785
ounces (oz)	grams (gm)	28.349
liters (l)	gallons (gal)	0.264
grams (gm)	ounces (oz)	0.035
	ENERGY	
British thermal units (BTU)	calories (cal)	1.996
British thermal units (BTU)	joules (j)	1054.35
calories (cal)	British thermal units (BTU)	0.004
calories (cal)	joules (j)	4.186
joules (j)	British thermal units (BTU)	0.0009
joules (j)	calories (cal)	0.239
	GRADIENTS	
degrees Fahrenheit/100 ft (°F/100 ft)	degrees Celcius/kilometer (°C/km)	1.822
degrees Celcius/kilometer (°C/km)	degrees Fahrenheit/100 ft (°F/100 ft)	0.055
	THERMAL CONDUCTIVITY	
$\frac{\text{millicalories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(mcal)}}{\text{(cm/sec °C)}}$	$\frac{\text{calories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(cal)}}{\text{(cm/sec °C)}}$	0.001
$\frac{\text{calories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(ucal)}}{\text{(cm/sec °C)}}$	$\frac{\text{millicalories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(mcal)}}{\text{(cm/sec °C)}}$	1000
	HEAT FLOW	
$\frac{\text{microcalories}}{\text{centimeter}^2\text{ second}}$ $\frac{\text{(ucal)}}{(\text{cm}^2\text{ sec})}$	milliwatts/meter^2 (mwatt/m^2)	41.871
milliwatts/meter^2 (mwatt/m^2)	$\frac{\text{microcalories}}{\text{centimeter}^2\text{ second}}$ $\frac{\text{(m)}}{(\text{cm}^2\text{ sec})}$	.024

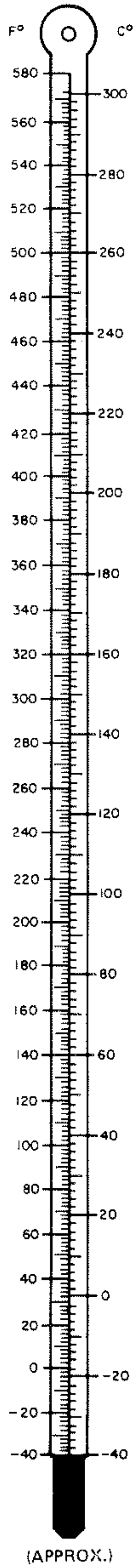


FIGURE 3. Temperature conversion graph.

GENERAL GEOLOGY

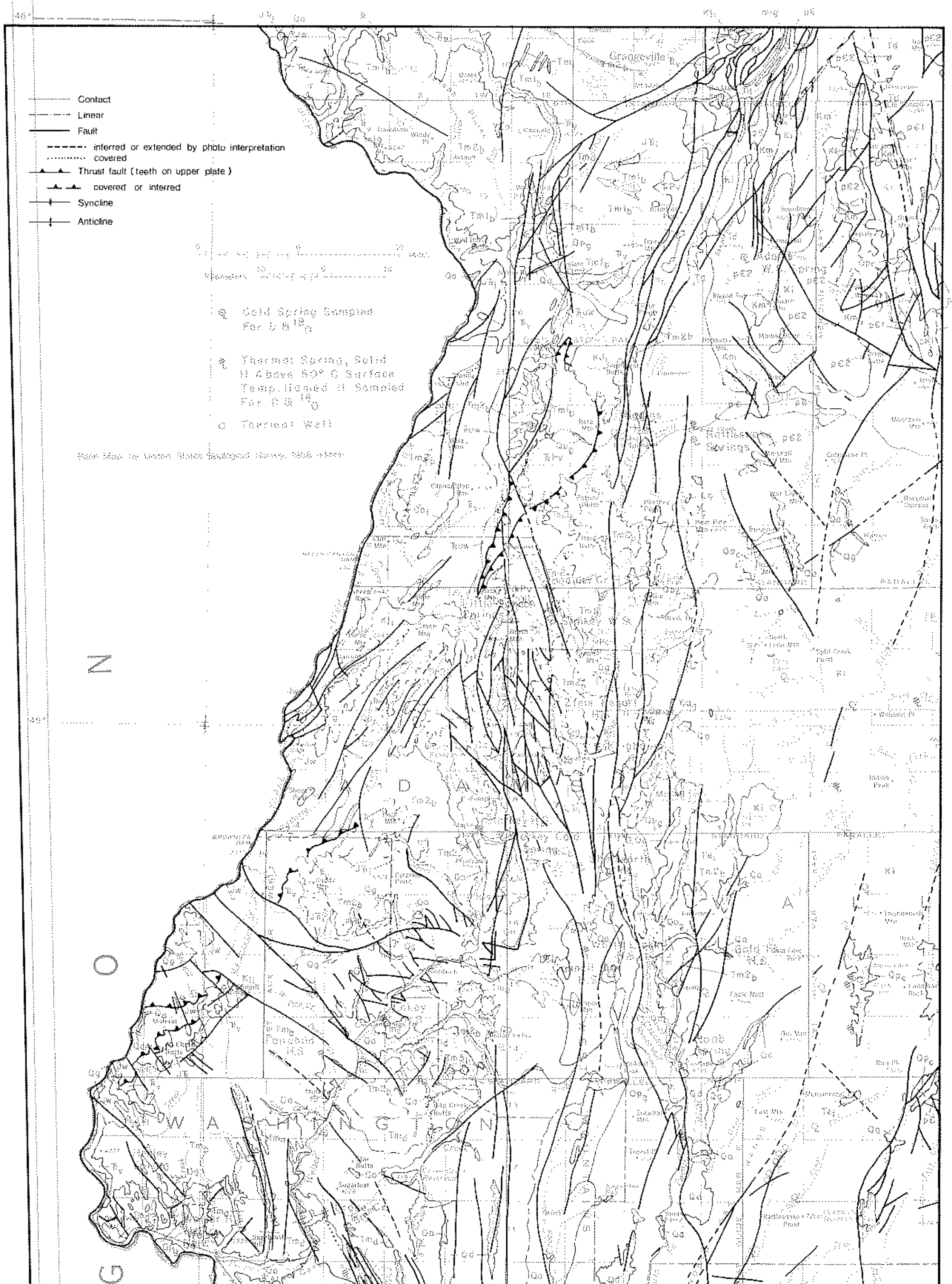
STRATIGRAPHY

The oldest rocks exposed in west-central Idaho are Triassic, or possibly Permian metavolcanic rocks, which crop out near the western border of the Idaho batholith. Lower Mesozoic intrusions of possible Triassic age are exposed in areas of the Snake River Canyon. Middle and Lower Triassic metabasalts are also exposed along the Snake River and cover extensive areas of the central portion of the study area. Some of these units have been intruded by Lower Cretaceous migmatites, exposed near the eastern margin of the study area near the border of the Middle Cretaceous Idaho batholith. The predominant rock type exposed in the area is Miocene plateau basalt subdivided on the map of Figure 4 into undifferentiated basalts, Upper Miocene Valley filling basalt flows, porphyritic Miocene basalt flows exposed on lower slopes, and finely crystalline Upper Miocene basalt flows exposed on upper slopes. Other rocks exposed in the area are Tertiary age continental rocks and include stream and lake deposits of Eocene, Miocene and Pleistocene ages generally associated with volcanism, Pleistocene upland valley deposits of probable glacial origin, Pleistocene outwash deposits consisting of fanglomerates and flood and terrace gravels, Quaternary colluvial deposits, and Quaternary alluvial deposits.

In the Weiser area, north of the hot springs, fine grained volcaniclastic rocks and arkrosic sandstone overlie andesitic and basaltic volcaniclastic rocks of Miocene age. Quaternary alluvial and colluvial deposits are found in the flood plain area of the Porters Flat and West Weiser Flat areas (Figure 5).

STRUCTURE

Capps (1941) recognized extensive faulting in western Idaho and its relation to high placer deposits. Hamilton (1962) reviewed available geologic literature in this region and described the Late Cenozoic structural features of west-central Idaho. The area is bordered on the east by the massive Salmon River Mountains composed predominantly of grantic rocks of the Idaho batholith. A north-south striking 80 km (50 mi) wide belt of post-Miocene, west-tilting, normal fault blocks, down thrown to the east, and west-dipping monoclines borders the batholith on the west. Bond's (1978) Geologic Map of Idaho shows some of the normal faults to be impressive in length, extending uninterrupted for about 80 km (50 mi). Some of these faults could be continuous for 160 km (100 mi) or more in length. This western Idaho Fault Belt, as named by Hamilton (1962, p. 512), is coincident with the western border zone or gradational belt of migmatites, gneiss, and quartz diorite schists on the western edge of the Idaho batholith described by Schmidt (1964). Hamilton


Contact
Linear
Fault
inferred or extended by photo interpretation
covered
Thrust fault (teeth on upper plate)
covered or inferred
Syncline
Anticline
Cold Spring Sampled For δ 18O
Thermal Spring, Solid if Above 50° C Surface Temp. Named if Sampled For δ & 18O
Thermal Well
Grangeville
Riggins
Fruitland
I D A H O
O R E G O N
W A S H I N G T O N
A D A M S
V A L L E Y

SUMMARY OF MAP UNITS*

See Idaho Bureau of Mines and Geology Information Circular 31 for general description of map units.

SEDIMENTARY ROCK
CONTINENTAL DEPOSITS

CENOZOIC UNITS

Q_a Quaternary alluvium; may contain some glacial deposits and colluvium in uplands.

Qp_a Pleistocene waterlaid detritus; may be distal deposits of glacial floods and outwash.

Q_g Quaternary colluvium, fanglomerate and talus plus some glacial debris in upland valleys.

Qp_g Pleistocene outwash, fanglomerate, flood and terrace gravels.

Qp_c Pleistocene upland valley deposits; commonly derived from alpine glaciation.

Qp_t Pleistocene till, moraines and similar unsorted glacial debris.

Q_d Quaternary detritus; generally basin-filling deposits of central and southern Idaho.

T_d Tertiary continental sediments; predominantly Upper Tertiary in age; subdivision are:

Tp_d Pliocene Stream and lake deposits; may be due to volcanic and block-faulting events.

Tm_d Miocene stream and lake deposits; generally associated with volcanic episodes;

DEEP MARINE-TO-TRANSITIONAL DEPOSITS

MESOZOIC UNITS

Jw Jurassic mixed marine detrital and volcanic rocs of western Idaho.

Ꞧuw Upper Triassic shale overlying reefal limestone and dolomite in west central Idaho.

$Ꞧ_v$ Middle and Lower Triassic metabasalt and submarine volanic-lastics of western Idaho.

IGNEOUS ROCK
EXTRUSIONS

Extrusive rock compositions may be denoted by subscripts: "b" basaltic; as basalt or lava.

CENOZOIC UNITS

Basalt

Tm_b Miocene plateau basalt flows of western Idaho; subdivisions are:

$Tm3_b$ Upper Miocene valley-filling basalt flows:

$Tm2_b$ Miocene basalt flows, commonly finely crystalline and exposed on upper slopes.

$Tm1_b$ Miocene basalt flows, commonly porphyritic and exposed on lower slopes.

INTRUSIONS

"i" intermediate; as granodiorite or diorite.

Tm_i Miocene intrusions including basalt feeder dikes and sills of western Idaho.

Te_i Eocene intrusions including large grantic plutons and dike swarms of central Idaho.

K_i Cretaceous plutons; probably includes unmapped older and younger crystalline bodies.

KJ_i Lower Cretaceous to Upper Jurassic intrusions in west-central Idaho.

$JꞦ_i$ Lower Mesozoic intrusions; localized near the Snake Canyon of western Idaho.

METAMORPHIC ROCKS

Moderate Metamorphism

Jw Jurassic marine wacke, volcanic and carbonate metasediments of western Idaho.

$ꞦP_v$ Triassic and possibly Permian submarine metavolcanic rocks of west-central Idaho.

Intense Metamorphism

p€ Precambrian, high-grade metamorphic rock; metasediment subdivisions are:

p€3 Kyanite-sillimanite calc-silicate bearing schist and gneiss; scapolite common;

p€2 Kyanite-sillimanite mica schist and micaceous quartzite;

p€1 Kyanite-sillimanite garnet-mica coarse-grained schist and gneiss; minor quartzite.

K_i Metamporphosed granitic intrusive rock; associated with pluton margins and stress areas.

pK_i Highly metamorphosed, probably Precambrian, instrusive rock; anorthosite common.

K_m Highly metamorphosed rock of central Idaho; age and origin of rock questionable.

mig Mixed, highly altered and migmatitic rocks; derived from imbrication and dynamic events.

* Summary of map units and geology from Bond (1978). Thermal springs locations from Mitchell and others (1980) Plate 1.

thought foliation in the migmatites and schists controlled normal faulting and that eastward dip of gneiss accounted for east-side down displacement of the normal faults.

Immediately to the west of the Western Idaho Fault Belt is the Columbia River Plateau province of irregular domal and anticlinal uplifts and northwest-trending normal faults as described by Hamilton (1962, p. 511). He called the mountain masses domes and diversely oriented anticlines. The anticlines were described as being bounded in part by the northwest-oriented normal faults which were a continuation of fault trends from the western Snake River Plain. Late Cenozoic structures here strike obliquely across pre-Tertiary structures in low-grade metamorphic rocks.

In the Weiser area, McIntyre (1976) mapped small scale synclines and anticlines to the west of Weiser Hot Springs and Shah (1966) interpreted opposite dipping beds north of the hot springs to be a larger scale, northwest-trending syncline and anticline developed in Miocene sandstone and andesitic volcaniclastic rock. McIntyre apparently interpreted the opposite dip direction and topographic breaks as due to faulting, as no anticlinal axis is shown on his map, but a northwest-trending fault appears near Weiser Hot Springs. The differences are important, as either could have major influence on thermal water occurrence here. Location of drilling sites to tap the resource could depend substantially on the type of structural control for the thermal water.

THERMAL WATER OCCURRENCES

Most thermal water occurrences in west-central Idaho are confined to an arcuate zone defined by the general courses of the South Fork Salmon and Weiser rivers. Springs that do not lie on this arcuate trend are generally to the east of this zone and include Cove and Crane creeks and White Licks Hot Springs. One thermal spring occurs near the Snake River on the western edge of the study area. The significance of this zone is not presently recognized, but might suggest that some springs could be hydrologically interconnected or have similar recharge areas. However, isotope data gathered for this study suggests separate systems for each spring, with recharge being local, but during a time of colder climate than that which prevails today (see next section).

In the study area, as shown by the geologic map (Figure 4), many thermal springs and wells are found on or near major mapped faults. Several others are found near contacts of differing rock units, primarily contacts between basalts units. Thermal wells generally have been drilled into Miocene stream or lake deposits or Quaternary alluvial deposits close to the contact with basalt rocks or with each other.

Very little drilling to any great depth has been done in the Weiser Hot Springs-West Weiser Flat area. The exceptions are as follows: A 244 m (800 ft) deep well (11N-6W-10cca2) drilled near Weiser Hot Springs, from which thermal water flows, was formerly used for greenhouse space heat and for the natatorium. Weiser Strat No. 2 well (11N-6W-15aa1) is 209 m (658 ft) deep and encountered 64°C (147°F) water near the bottom (issuing from basalt?). This well was drilled by Phillips Petroleum Company for geotechnical information and then plugged. Weiser Strat No. 3 well, also drilled by Phillips, is 473 m (1550 ft) deep and bottomed in basalt. No water was reported in the log of this well. Well 11N-5W-33bc1 was drilled by the city of Weiser for municipal use. Cross sections from available water well drillers' logs and the geotechnical holes are shown in Figure 6. The interesting thing about the well logs, hence the cross sections, is the association of thermal water (<100°C) with what water well drillers' term "blue clay." "Blue clay" is associated with thermal water in the Crane Creek, Parma, Nampa-Caldwell, and Boise areas of the western Snake River Plain and has been noted in drillers' logs in thermal wells as far east as McCammon, Idaho, in Bannock County. In the Nampa-Caldwell area a "blue clay" acts as an aquitard or cap rock, separating non-thermal water (above) from thermal water found below the "blue clay" (Anderson and Wood, 1981). The blue color may be due to finely disseminated pyrite found in the clay, which oxidizes to iron oxide in a few hours to a few days on exposure to the atmosphere. Upon oxidation, the clay turns brown, hence is rarely recognized in outcrops.

STABLE ISOTOPE INVESTIGATION

Isotopes are two forms of the same element which differ only in the number of neutrons (uncharged atomic particles) in the nucleus of the atom. This means that different isotopes of the same element will differ only in their relative mass. It is this mass difference that governs their kinetic behavior and allows isotopes to fractionate during the course of certain chemical and physical processes occurring in nature.

The four stable isotopes that have proven most useful in water resource evaluation are hydrogen (^{1}H or H), deuterium (^{2}H or D), oxygen 16 (^{16}O), and oxygen 18 (^{18}O). These isotopes make up 99.9 percent of all water molecules.

Isotopic compositions are reported in "δ" notation in parts per thousand (per mil = $^{o}/oo$) relative to Standard Mean Ocean Water (SMOW) as defined by Craig (1961a), where i = $[(R_i/R_{std})-1] \times 1000$. R_i equals either $^{18}O/^{16}O$ or D/H while i and std represent the sample and standard, respectively.

EXPLANATION

Geology and Rock Description by McIntyre (1976)

Qa SURFICIAL DEPOSITS (HOLOCENE AND PLEISTOCENE)--Chiefly alluvium and flood plains and terraces; also includes laminated silts on West Weiser Flat and high level gravels along the Snake River north and west of Porters Island that may be related to the Lake Bonneville flood. Also contains sand dunes near Olds Ferry

Qa FLOOD-PLAIN ALLUVIUM (HOLOCENE)--Along Warm Springs Creek and adjacent streams

GRAVEL DEPOSITS CAPPING PEDIMENT SURFACES (HOLOCENE? AND PLEISTOCENE)--In Warm Springs Creek-Hog Creek area

Qp_1 First (lowest) gravel deposit

Qp_2 Second (middle) gravel deposit

Qp_3 Third (highest) gravel deposit--Silica cementation (silcrete) locally developed in higest gravels adjacent to Henley Basin Road (K. L. Pierce, oral commun., 1974)

Ql LANDSLIDES, EARTHFLOWS, AND RELATED DEPOSITS (HOLOCENE AND PLEISTOCENE)--Only large masses shown

QTh HYDROTHERMALLY ALTERED SEDIMENTARY ROCKS (HOLOCENE? TO MIOCENE)--Irregular, discontinuous silicified zones in volcaniclastic rocks and sandstone; distinguished from ordinary silica-cemented arkosic sandstone by limonite staining and also, commonly, by obliteration of primary textures. Locally prospected for Au and Hg. Alteration chiefly fracture controlled, but some stratigraphic control locally present (example: on Haystack mountain, and 2,000 ft of 610 m south of sumit of Haystack; too small to show on map). Known alteration is confined to three areas: (1) in sandstone on and south of Haystack; (2) sporadically along a belt extending northeastward from vicinity of the mine which is west of Barton Reservoir (now called the Blue Dog Tunnel, apparently the Modoc mine of Varley and others, 1919) to margin of Mann Creek valley; and (3) near northwest-trending escarpment east of Weiser River (too small to show on map). At two localities openwork breccias are present: on silicified knob 1,000 ft (305 m) northeast of portal of Blue Dog tunnel, and in quarry east of U.S. Highway 95 near west margin of Mann Creek valley, in SW 1/4, sec. 25, T. 12 N., R. 5 W. Available analyses are listed in Table 2.

Ti INTRUSIVE ROCKS (MIOCENE)--Dikes, plugs, and quasi-concordant masses of basalt or basaltic andesite; those near Indian Head Mountain commonly are altered and contain prominent calcite and green phyllosilicates. Textures range from nearly holocrystalline ophitic to very fine grained intersertal (table 1, column C). Dike north of U.S. Highway 95 northeast of Barton Reservoir is basaltic andesite with prominent olivine pseudomorphs (table 1, column H). Whole rock K-Ar age of dike is 10±0.6 m.y. (analysts: R. F. Marvin, H. H. Mehnert, and Vio et Merritt)

Ts SEDIMENTARY ROCKS (MIOCENE)--Fine-grained volcaniclastic rocks and arkosic sandstone. Includes pumice lapilli tuff and fine vitric tuff (commonly altered to clay) containing sparse crystals of plagioclase, quartz, and biotite; locally contains beds rich in plant debris or thin beds of lignite. Arkosic sandstone is coarse grained to very coarse grained and contains subangular to subrounded grains of quartz, potash feldspar, plagioclase, biotite, and muscovite, and small amounts of amphibole, zircon, sphene(?) and, in some samples, trace amounts of undetermined high-relief minerals. Samples near Indian Head Mountain contain small amounts of cryptocrystalline volanic rock fragments, some of which contain epidote, suggesting the pre-Tertiary metavolcanics as a possible source. Uncemented sandstone generally does not crop out; most exposures are bold ledges cemented by silica, chiefly opal. Silica in well-cemented ledge-forming rock occurs as filling or lining of openings between grains, indicating a high porosity for the rock before cementation; uncemented sandstones commonly have abundant fine matrix and a consequently low porosity. A cobble conglomerate containing gray plagioclase porphyry clasts foreign to the area occurs at propsect north of Crane Creek

Tl FLOWS AND VOLCANICLASTIC ROCKS (MIOCENE)--Chiefly lava flows of basaltic aspect, with associated volcaniclastic rocks, andesitic and latitic flows also present. Flows of basaltic aspect commonly are nonporphyritic (exceptions have plagioclase or olivine phenocrysts) and are of two textural types: uniformly fine-grained, or ophitic containing large clinophyroxenes conspicuous in hand specimen. All contain calcic plagioclase, clinopyroxene, and opaque oxides (chiefly magnetite), must also contain olivine or olivine pseudomorphs; many contain apatite as needles or tubules. Some are slightly diktytaxitic. A few contain minor carbonate, often as filling of diktytaxitic openings. Analyses (table 1) show that many of these flows are andesites. Latitic and other andesite flows are described in table 1 (columns B, G, J)

CONTACT--Dashed where approximately located; queried where existence uncertain

FAULT--Dashed where approximately located; dotted where concealed; queried where existence uncertain. Bar and ball on downthrown side

ANTICLINE--Showing crestline

SYNCLINE--Showing troughline. Dashed where approximately located

STRIKE AND DIP OF BEDS OR LAVA FLOWS--Symbol without dip number is approximate determination from aerial photographs

APPROXIMATELY HORIZONTAL BEDS OR LAVA FLOWS

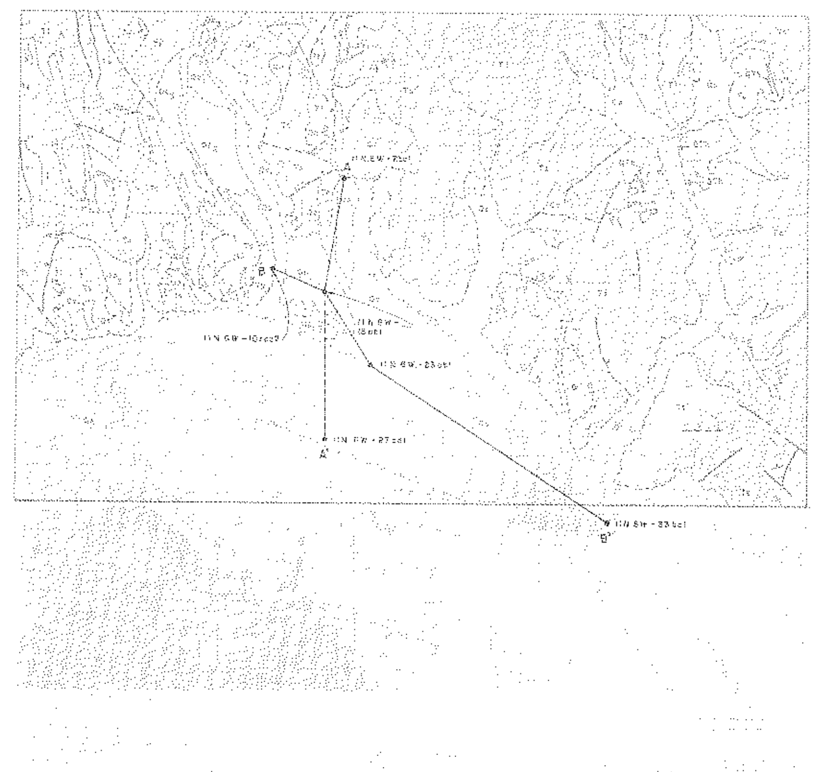


FIGURE 5. Geologic map of a portion of the Olds Ferry Wuadrangle showing locations of wells for stratigraphic cross sections.

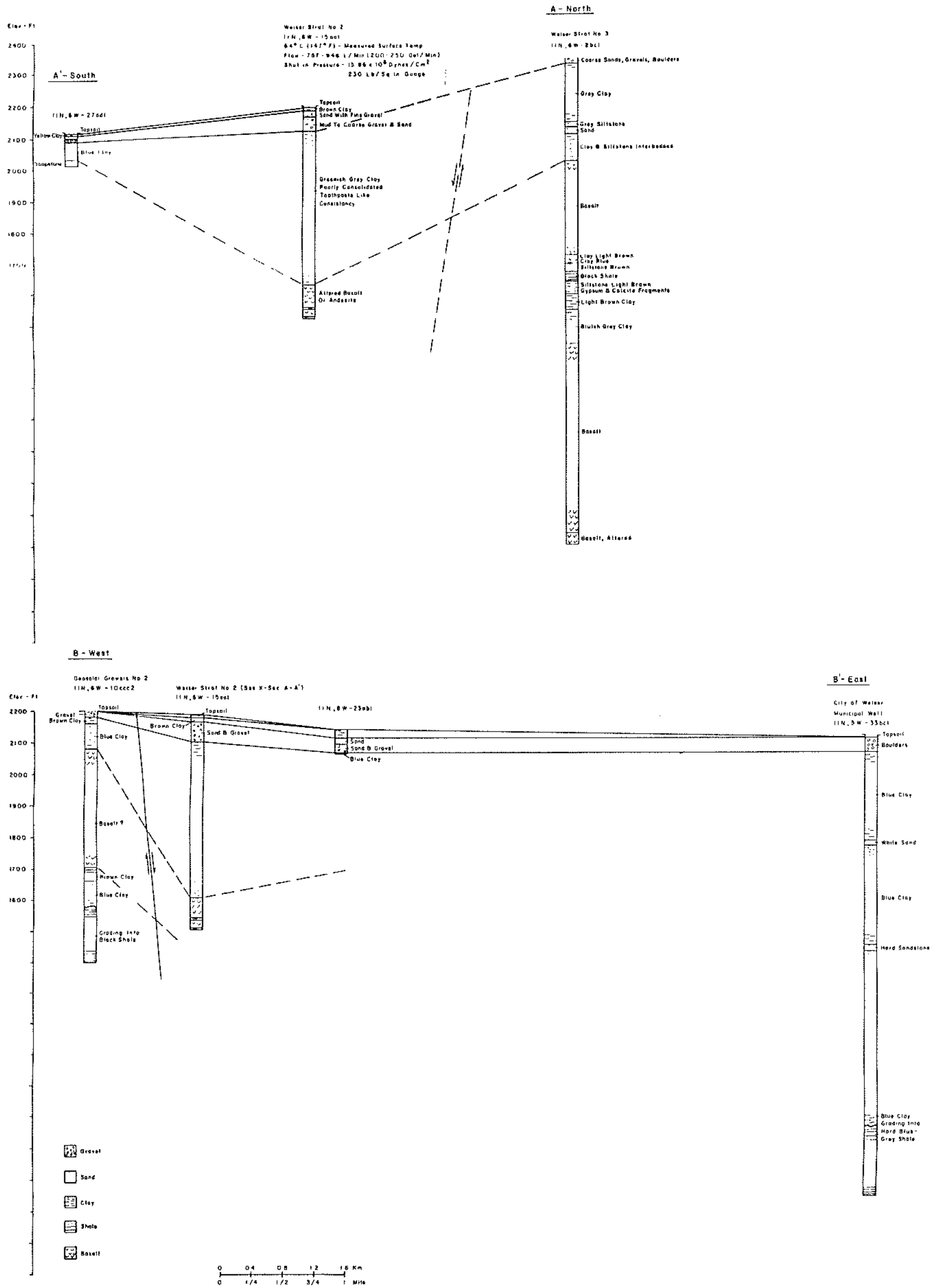


FIGURE 6. Generalized stratigraphic cross section across West Weiser Flat area.

The result of isotopic fractionation during evaporation of ocean water and subsequent condensation of vapor in clouds is that fresh (meteoric) water is generally depleted in ^{18}O and D (enriched in ^{16}O and H) compared to seawater. The isotopic variations of water in rain, snow, glacier ice, streams, lakes, rivers, and most nonthermal groundwaters are extremely systematic; the higher the latitude or elevation, the lower (more depleted in heavy isotopes) the δD and $\delta^{18}O$ values of the waters. On the basis of a large number of analyses of meteoric waters collected at different latitudes, Craig (1961b) showed that the $\delta^{18}O$ and δD values relative to SMOW are linearly related and can be represented by the equation:

$$\delta D = 8\delta^{18}O + 10$$

which is plotted in Figure 7. Groundwater sampled in an area whose isotopic composition plots on the trend (meteoric water) line are generally considered to be meteoric waters. Gat (1971) reported that incongruous results in isotope hydrology studies have generally been interpreted to mean: (1) geographic displacement of groundwaters by flow, (2) recharge from partially evaporated surface waters, (3) recharge under different climatic conditions, (4) mixing with nonmeteoric water bodies--brines, seawater, connate, metamorphic or juvenile waters, (5) differential water movements through soils or aquifers which result in fractionation processes (membrane effects), and (6) isotopic exchange or fractionation between water and aquifer materials. Several of these processes tend to be distinctive, either in enriching or depleting the waters in heavier isotopes, and can be recognized. Others tend to be similar in results; therefore, interpretations may be ambiguous.

SAMPLING

Mitchell and others (1980, pp. 21-23) noted the regular spacing of thermal springs in Idaho along narrow curved or arcuate zones. This was thought due to the regular spacing of structural features (jointing, faulting, etc.) common to all springs along the arcuate trend. This could imply hydraulic interconnection for some of the thermal springs. Young and Whitehead (1975, p. 27) noted that areas to the north and east of Weiser, Crane Creek, and Cove Creek hot springs could be areas of recharge to these spring systems. Samples were taken along the length of two of the arcuate zones defined in the Weiser and Little Salmon River drainage basins to determine isotopic compositions of thermal water along their length. Sites for isotopic sampling along the arcuate trends were chosen on the basis of surface temperature and geographic location. All springs were sampled during the fall of 1981 to insure sampling of perennial discharge. A total of 24 samples were analyzed by mass spectrometry by Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, Massachusetts. On the basis of duplicate samples and analyses, the data appear to be precise within 1 $^{o}/oo$ for D and 0.2 $^{o}/oo$ for ^{18}O. These data are given in Tables 2 and 3 and sample locations are shown on Figure 4. The data are shown plotted as δD versus $\delta^{18}O$ in per mil units on Figure 7.

OBSERVATION

From Table 2, the range of δD values for thermal waters (>20°C) sampled during this investigation is from -139 to -160 $^{o}/oo$. The range of $\delta^{18}O$ values is from -12.3 to 19.1 $^{o}/oo$. From Table 3, for cold waters (<20°C) sampled in this area, the range of δD values is from -120 to -140 $^{o}/oo$ and the range of $\delta^{18}O$ values is from -15.0 to 17.5 $^{o}/oo$.

Figure 7 shows that none of the cold waters sampled fall on the meteoric water line defined by the equation $\delta D = 8\delta^{18}O + 10$ on the figure. The figure shows that most of the sampled cold springs fall on lines of slope = 2. Lines of slope = 2 can be drawn through many of the thermal springs as well.

In general, thermal water is depleted in D by 10 to 20 $^{o}/oo$ relative to cold water sampled in the same area. Isotope values for thermal waters plot in three separate locations on Figure 7. Isotope values for several springs plot with a center at approximately a δD of -140 $^{o}/oo$. Another larger group appears centered near a δD value of -150 $^{o}/oo$. A third group of four thermal springs appears centered near a δD value of -157 $^{o}/oo$. Thermal waters range widely in $\delta^{18}O$ values (>6 $^{o}/oo$). Cold waters have a much more restricted $\delta^{18}O$ range (<2 $^{o}/oo$).

Figures 8 and 9 are plots of δD and $\delta^{18}O$ versus latitude and longitude for sampled springs and wells. Such plots can be informative for regional data and were made to determine if thermal water isotope values were latitude and longitude related. Also, anomalous values can more easily be observed and interpreted from such plots. The plots represent a first iteration or approximation in an effort to observe the latitude and longitude effects and more clearly see the magnitude of such effects. The plots also show the data as being consistent, which inspires confidence in the results of the analyses reported by the analytical laboratory. Any errors made in sampling or analytical procedures are more easily recognized.

Coefficients of determination (r^2) for the regression lines drawn through the thermal water data on Figures 8 and 9 are shown on the figures near each line, and labled C.D. The slope of each line (m) is also given. The obvious anomalous values or deviations from each line for each figure were omitted during the regression calculations, as were the cold water data. Values of r^2 close to 1 represent a good fit of the line to the data used in the calculations. Values close to zero represent a poor fit.

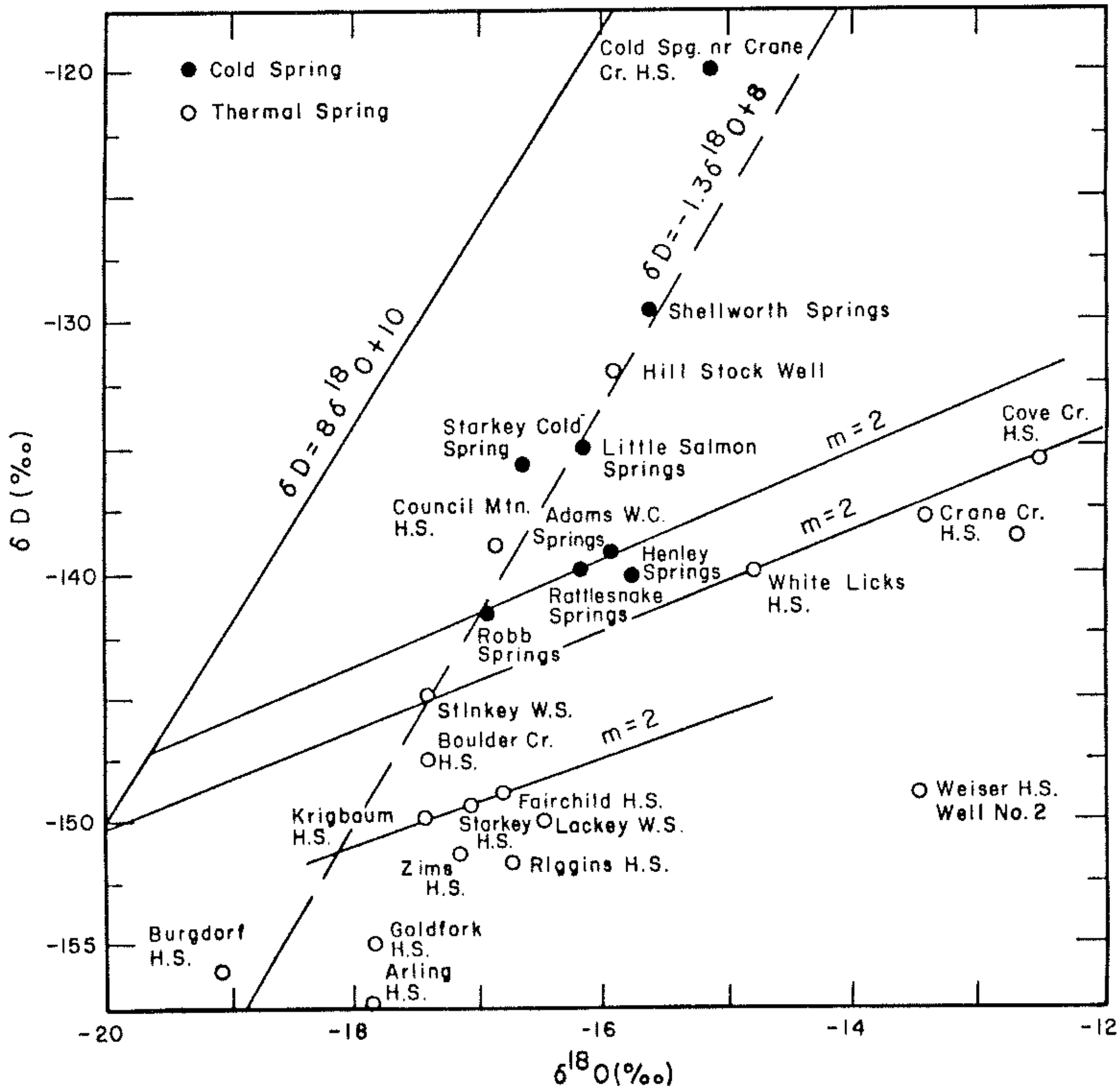


FIGURE 7. Isotopic composition of thermal and non-thermal water from selected springs, wells and surface waters in the Weiser and Little Salmon River drainages and adjacent areas.

TABLE 2

Isotope sample locations, measured surface temperatures, latitude and longitude of sample point, δD and $\delta^{18}O$ values from thermal water in the Weiser and Little Salmon River drainages, west central Idaho.

Spring/Well Name & Identification Number	Surface Temperature	Latitude	Longitude	δD	$\delta^{18}O$
Riggins H.S. 24N-2E-14dbdls	41	45.4162	116.1722	-152	-17.7
Burgdorf H.S. 22N-4E-1bdcls	45	45.2768	115.9124	-156	-19.1
Boulder Creek Resort 22N-1E-34dadls	28	45.2009	116.3115	-147	-17.4
Stinkey W.S. 21N-1E-23abals	31	45.1518	116.2962	-145	-17.4
Zims Resort 20N-1E-26ddals	62	45.0385	116.2913	-152	-17.2
Krigbaum H.S. 19N-2E-22ccals	43	44.9714	116.2034	-150	-17.4
Starkey H.S. 18N-1W-34dbbls	55	44.8528	116.4421	-149	-17.1
White Licks H.S. 16N-2E-33bccls	60	44.6814	116.2281	-140	-14.8
Gold Fork H.S. 16N-4E-35ccbls	53	44.6756	115.9427	-155	-17.8
Council Mountain 15N-1E-2bddls	68	44.6691	116.3052	-138	-16.9
Arling W.S. 15N-3E-13bbcls	32	44.6404	116.0448	-157	-17.9
Lakey H.S. 14N-2E-6bbals	70	44.5860	116.6304	-150	-16.4
Fairchild H.S. 14N-3W-19cbdls	52	44.5313	116.7535	-148	-16.8
Hill Stock Well 11N-6W-3dcbl	28	44.3143	117.0402	-133	-15.9
Crane Creek H.S. 11N-3W-7bdbls	74	44.3064	116.7455	-134	-13.8
Weiser Hot Springs Well #2 11N-6W-10acc2	77	44.2995	117.0497	-149*	13.4*
Cove Creek H.S. 11N-3W-9cccls	78	44.2112	116.7100	-134	12.4

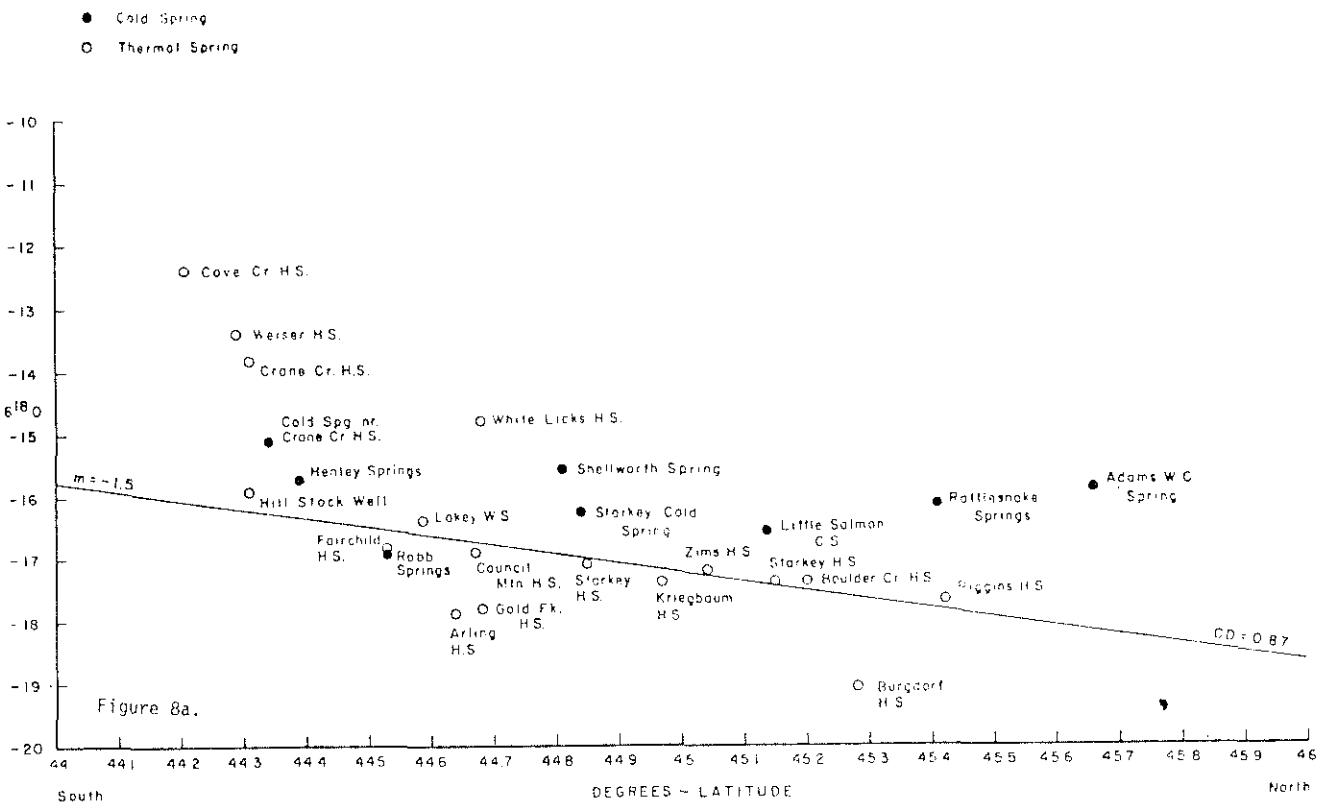
*Data from Rightmire and Others, 1976

TABLE 3

Isotope sample locations, δ D and $\delta^{18}O$, measured surface temperatues and latitude and longitude of cold water sample points in the Weiser and Little Salmon River drainages and adjacent areas.

Spring/Well Name and Identification Nubmer	Surface Temp.	Latitude	Longitude	δD	$\delta^{18}O$
Adams Work Center Cold Springs 27N-3E-23ddbls	6	45.6579	116.043	-138	-15.9
Rattlesnake Springs 24N-4E-19bccls	6	45.4075	116.019	-140	-16.2
Little Salmon R. Cold Spg. 21N-1E-24ccdls	6	45.1394	116.286	-136	-16.6
Cold Spring nr. Starkey H.S. 17N-1W-1ddls	7	44.8327	116.397	-136	-16.3
Shellworth Springs 17N-2E-15babls	6	44.8165	116.204	-129	-15.6
Robb Springs 14N-4E-23cccls	6	44.5284	115.944	-142	-16.9
Henley Springs 12N-7W-11dacls	8	44.3887	117.137	-140	-15.7
Cold Creek nr. Crane Creek H.S. 12N-4W-34abbls	8	44.3398	116.801	-120*	-15.1*

*Data from Rightmire and Others, 1976.



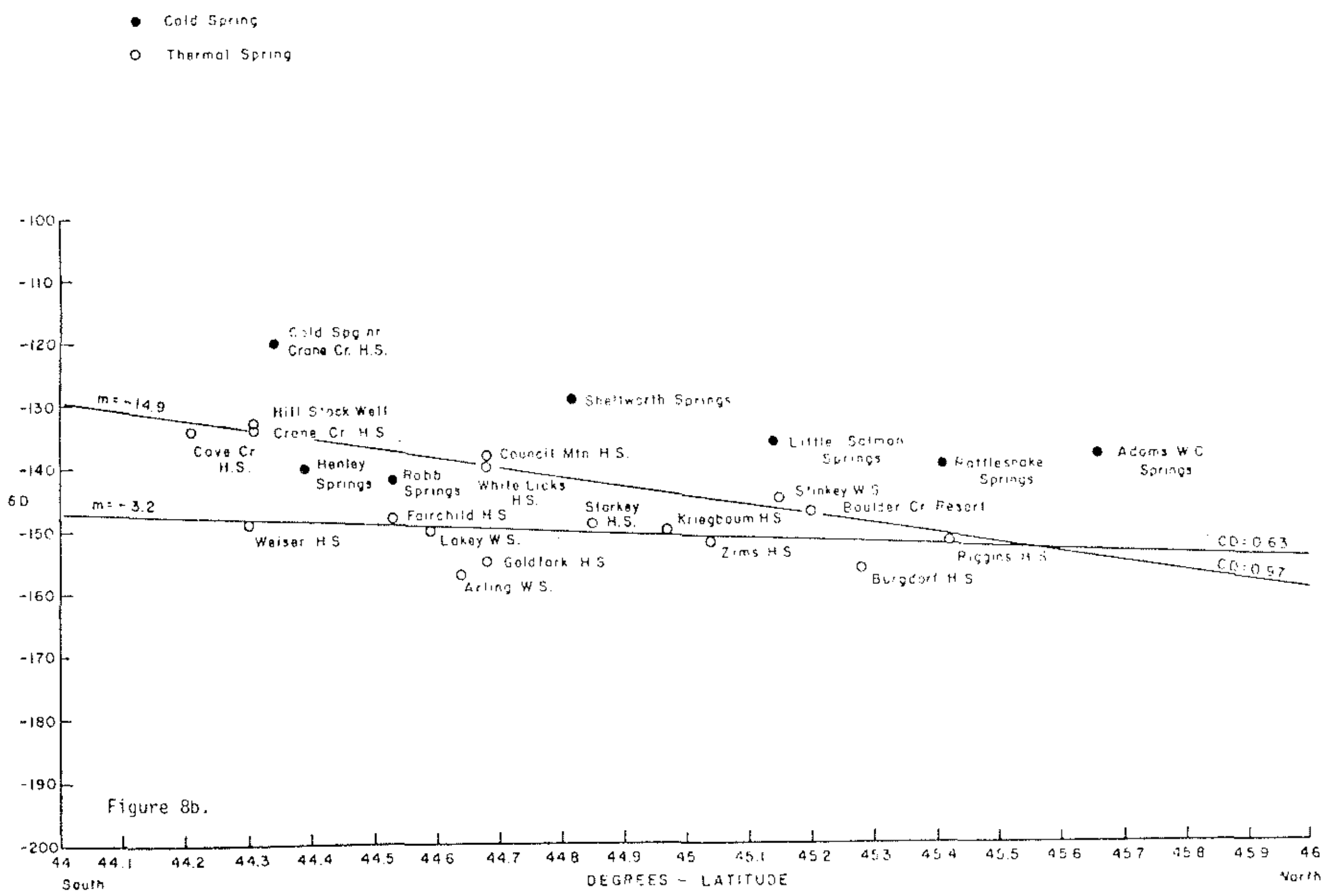


FIGURE 8. Latitude versus δD and $\delta^{18}O$ from selected springs wells and surface waters in the Weiser and Little Salmon River drainages and adjacent areas.

The coefficients and the data plots, in general, show a good relationship between latitude and longitude versus δD and $\delta^{18}O$ for many of the sampled thermal waters.

Thermal waters showing the most obvious anomalies or deviations from the latitude line plots of Figure 8 are Arling, Goldfork, and Burgdorf (depleted in D and ^{18}O with respect to the latitude line plot), Crane and Cove creeks and White Licks hot springs waters which show enrichment in ^{18}O and depletion in D, relative to the latitude line plots.

The obvious deviations on the longitudinal line plot (Figure 9) are Burgdorf (enriched in ^{18}O), Starkey, White Licks, and Crane Creek and Cove Creek hot springs waters. Weiser Hot Springs water is enriched in ^{18}O and depleted in D relative to the longitudinal line plots.

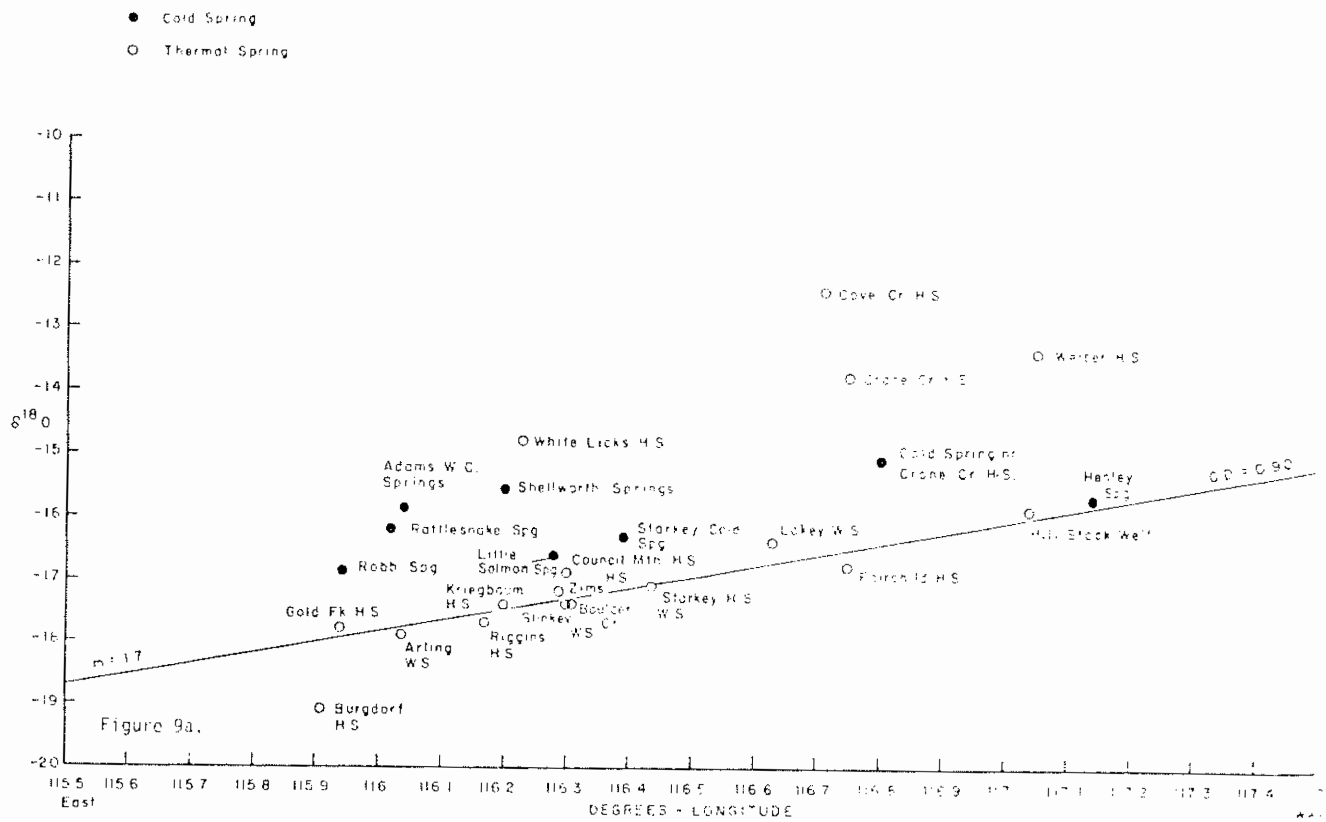
The data point distribution on the D versus latitude and longitude plots appears to be bimodal or even trimodal (represent two or even three populations or clusters). The $\delta^{18}O$ plots may also exhibit two populations although the number of points and scatter in the data make this observation questionable.

On most of the plots, the scatter in cold water data prevents meaningful regression analysis. An exception may appear for some cold water data on Figure 8b, where deuterium in cold water seems to be latitude related. The line which could be drawn from Cove Creek cold springs through Rattlesnake Springs has a slope near that of the regressed line, with slope (m) = 3.2, on the same figure. On the $\delta^{18}O$ versus latitude plot (Figure 8a), the cold water data appears to be bimodal, with both lines having slopes near that of the thermal water line.

It should be noted that a perfect correlation in the thermal and non-thermal isotope data is not expected because of possible microclimatic differences in recharge areas for individual springs and subterranean travel time differences, which introduces variability in recharge timing. Most of the data, however, appear to be reasonably consistent.

DISCUSSION

The progressive depletion of D and ^{18}O with higher latitude and toward the interior of the continent shown by most thermal water, plotted on Figures 8 and 9, is reminiscent of the generalized trend in modern day precipitation which also shows this general distribution. Cold waters in other parts of Idaho have been shown to be essentially modern waters (Young and Lewis, 1980; Lewis and Young, 1980). The similar slope of the thermal water line with slopes of lines that could be drawn through cold water data points on the latitude plots indicates that the magnitude of the latitude effect in isotopic fractionation might be



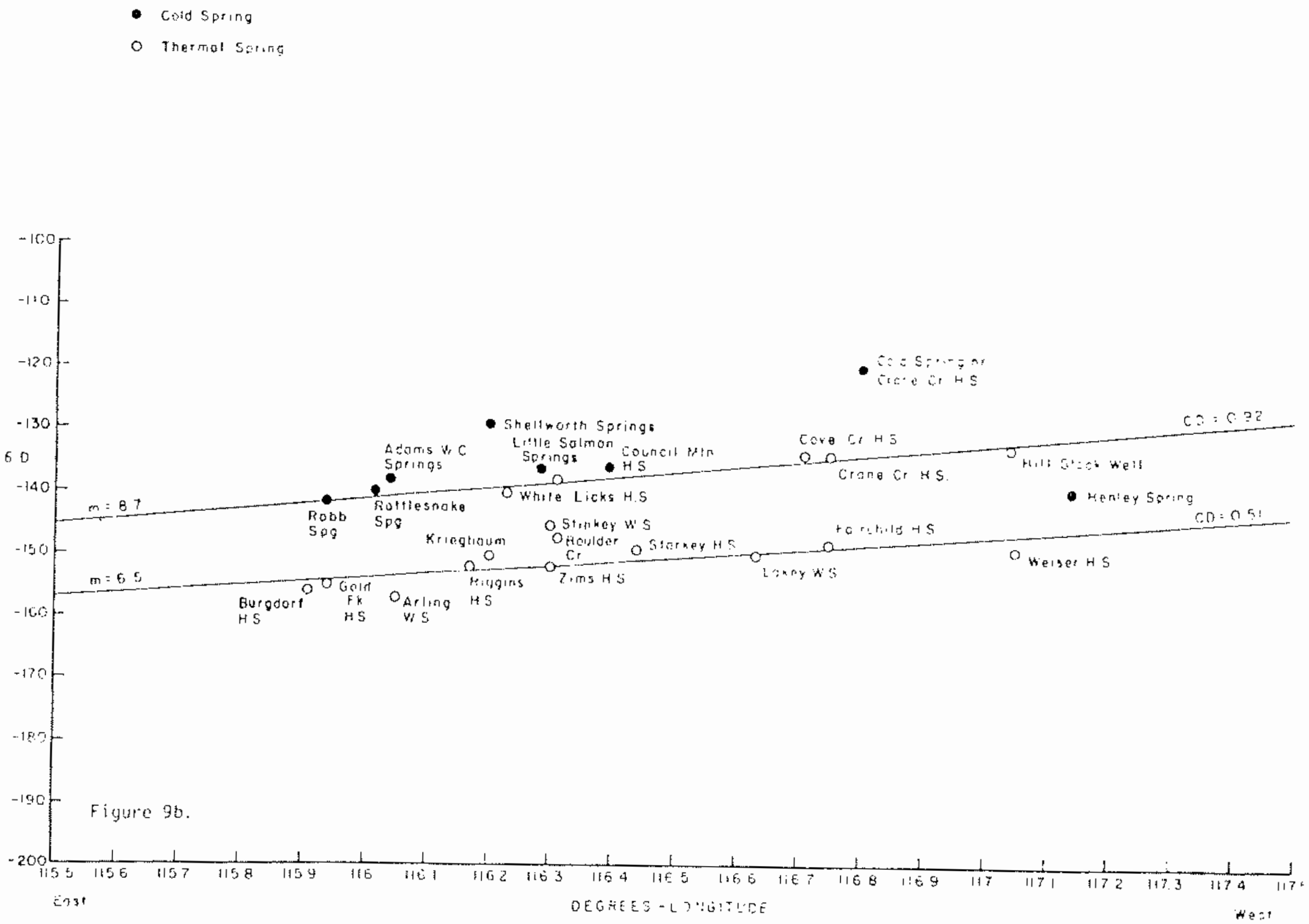


FIGURE 9 Longitude versus δD and $\delta^{18}O$ from selected springs, wells and surface waters in the Weiser and Little Salmon River drainages and adjacent areas.

similar for both hot and cold waters. However, no lines have been drawn on the plots through the cold water data points in order to emphasize that this conclusion should be regarded as speculative as so few cold water data points are available on which to base this observation. The general depletion in D and ^{18}O relative to cold water, as revealed by Figure 7, indicates that thermal waters cannot be derived directly, or are not related to cold groundwaters from the same general area. Thermal waters that show depletion in D and ^{18}O relative to cold waters have been interpreted as old waters which fell as rain or snow during an extended time period when the climate was colder than that prevailing today, as suggested by Rightmire and others (1976), for the Bruneau-Grandview area. Old meteoric water appears plausible as a source for most thermal water in this area as (1) water moves only very slowly through confined aquifers and may take thousands of years to circulate to depths where it is heated by hot rocks and returned to the surface again and (2) age dating of isotopically lighter thermal water in eastern Idaho (Mayo, 1980, personal communication) and in the Boise area give Pleistocene (ice age) age dates (>11,000) years for most thermal waters tested.

The general fit of most of the isotope data to the straight-line latitude and longitude plots and the fact that the waters from each individual spring system are unique isotopically implies that recharge to each spring system was, for the most part, local meteoric water recharge and that a single major recharge area supplying all or most of the springs does not exist. The thermal springs in this area probably are individual hydrologic systems with little or no hydraulic interconnections.

Deviations from straight-line fit greater than $\pm$ 1 $^{o}/oo$ on the δD plots and $\pm$ 0.2 $^{o}/oo$ on the $\delta^{18}O$ plots (the analytical precision) might be due to local variations in conditions of recharge such as elevation or localized latitudinal or longitudinal differences, perhaps mixing of isotopically lighter thermal water with heavier cold groundwaters, or isotopic exchange reactions that have occurred in the water deep in the systems.

Depleted values on both latitude line plots (Figures 8a and b) in Arling, Gold Fork, and Burgdorf hot spring waters might be explained, in part, as an inland or longitudinal effect. Isotopic data from Arling and Gold Fork waters fall very near the longitudinal lines on Figures 9a and b, indicating local recharge. Their inexact fit, slight enrichment in ^{18}O (Figure 9a), and slight depletion in D indicate source waters could be from precipitation that fell more easterly, or at higher elevations or both from where the springs presently discharge. Their slightly differing isotopic water compositions indicate recharge areas slightly removed from one another. Many of the thermal springs showing enrichment in ^{18}O and D on Figures 9a and b (Stinkey and Boulder creeks) might, in part, be explained as a latitude or elevation effect. They do fall near the latitude line of Figures 8a and b.

Certain spring waters show marked enrichment in ^{18}O on both latitude and longitude line plots. These include Weiser, Crane, and Cove creeks and White Licks thermal waters. These thermal waters, for reasons outlined by Young and Mitchell (1973), Young and Whitehead (1975) and Mitchell and others (1980), are thought to have been elevated in temperatures at, or in excess of 140°C. The normal δD values relative to the latitude line plot of Figure 8b for Crane and Cove creeks and White Licks thermal waters indicates this hypothesis. The depleted δD values for Weiser thermal waters are unusual. It may mean Weiser waters are a separated steam phase, highly enriched in ^{18}O due to rock water interactions and then subsequently depleted by a lesser amount in both ^{18}O and D by steam separation, or the area of recharge is not local, but to the north where precipitation values similar to Lakey, Fairchild, Starkey, and Krigbaum waters accumulated. Weiser waters then, subsequently, underwent ^{18}O enrichment processes through isotopic exchange at elevated temperatures.

Sampled non-thermal water may not represent unaltered modern-day precipitation as they do not fall on the meteroic water line of Figure 7. This may be due to evaporation before recharge. Alternatively, some of the non-thermal water may represent unaltered modern-day precipitation which, due to subregional climatic differences, do not plot on the standard meteroic water line. Waters from Rattlesnake, Henley, and Adams Work Center cold springs might even represent older cold waters as they seem to plot more in the region of thermal water on Figure 7. The non-thermal water samples probably do, however, represent water that could be one end member or component in mixing of thermal and non-thermal groundwater.

There is some evidence to suggest the lines of slope 2 on Figure 7 may be attributable to the latitude and/or longitudinal fractionation effect. Robb, Rattlesnake, and Adams Work Center cold springs all lie along the same lines on Figures 7 and 9b. Kriegboum, Starkey, Fairchild, Zims, and Lakey, which lie along lines of slope 2 on Figure 7, lie along the line of slope -1.5 on Figure 8a.

If the thermal waters are indeed old waters, and similar latitude effect operated at the time of precipitation of these waters, as it does today, which could be indicated by Figure 8, then Figures 8 and 9 indicate little, if any, mixing of colder, younger, isotopically heavier groundwater with older, isotopically light, thermal waters plotted on the figure. Mixing of this nature should cause the plotted point to fall in the enriched region of all the figures between the thermal and nonthermal data points by a value proportional to the cold water volume involved in mixing, provided all latitude and longitude effects are accounted for in the plots. There are no sampled thermal discharges, in the author's opinion, that conclusively prove mixing. Some points do fall in the enriched region of some of the graphs, i.e., the Glen Hill well and Stinkey Warm Springs. These thermal water discharges have lower measured surface temperatures than all other thermal discharges sampled during the course of this study. These may or may not be mixed waters. Data are insufficient to tell. These conclusions should have bearing on interpretation of the chemical geothermometer that have been made by Young and Mitchell (1973), Young and Whitehead (1975) and Mitchell and others (1980) for thermal water discharges in the Weiser River and Little Salmon River drainage basins.

GRAVITY AND MAGNETIC MEASUREMENTS

BOUGUER GRAVITY MAP

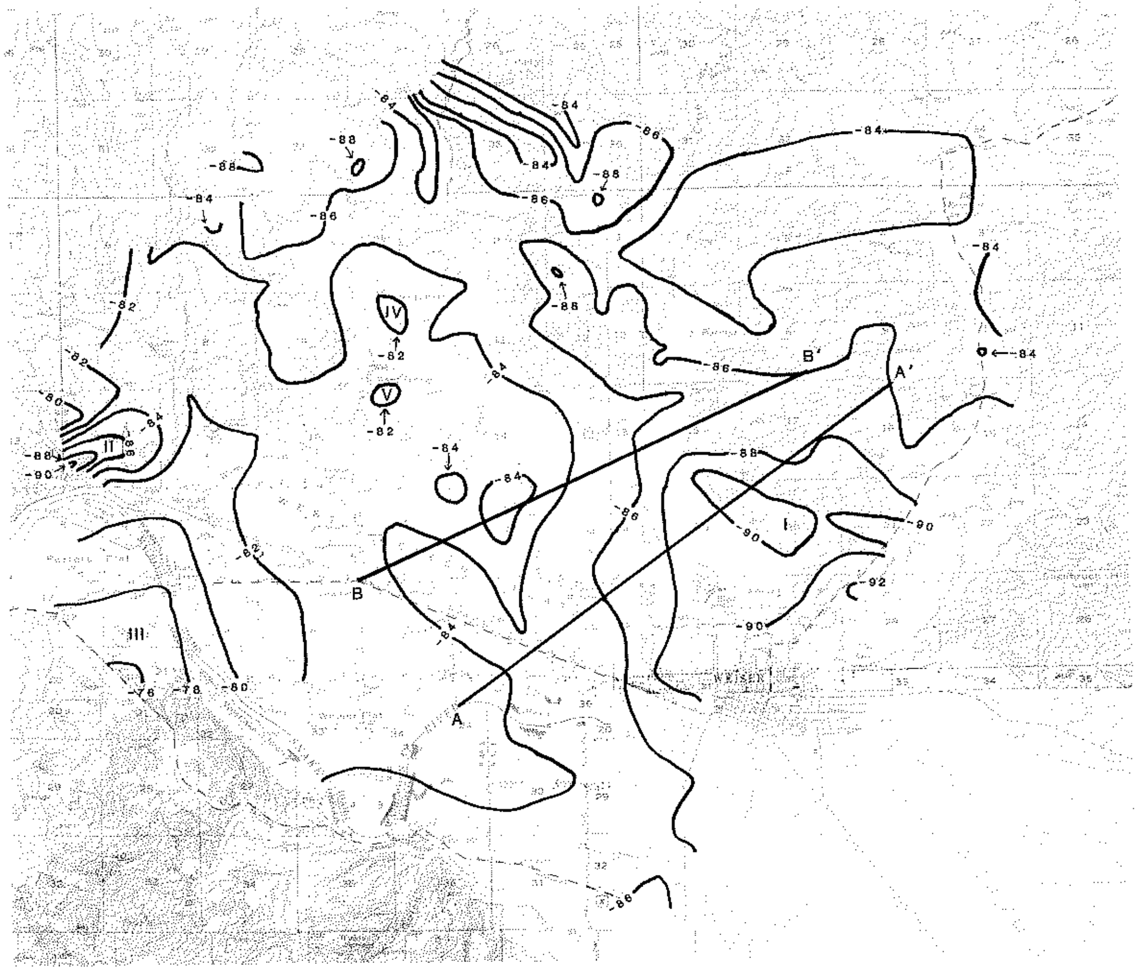
Analysis of the gravity data obtained in this study resulted in the finding of gravity anomalies on both the Bouguer anomaly and the residual gravity maps. These anomalies reflect local density variations in the underlying rocks. Such density variations could be either vertical or horizontal, and can be caused by structural or lithologic change. Anomalies are interpreted with the help of magnetic data from this study and data from previous geologic studies which provide more geologic control. Gravity data alone cannot be uniquely interpreted since a given gravity anomaly can be produced by a large number of structural and stratigraphic models.

On the Bouguer anomaly map, Figure 10, there are several distinct anomalies present. All of which are of minor intensity. These anomalies can be differentiated into positive and negative with relation to the background values.

Figure 10 shows two distinct negative anomalies, anomalies I and II. Anomaly I is observed approximately 1.6 km (1.0 mi) north of the city of Weiser and trends to the northwest. Anomaly II is located at the edge of the highland north of Porters Island. Its southern boundary appearing to terminate on the margin of the highland. The low, north of Weiser proper, has bilateral symmetry which suggests that the cause for the southwest boundary mirrors that of the northeast-trending boundary.

On Figure 10, the positive anomalies or gravity highs are minor in value and extent, with the exception of the high south of Porters Flat. This major high, anomaly III, increases to the southwest, and may be a portion of an extensive gravity high that

BOUGUER ANOMALY WEISER AREA, IDAHO



0 1 2 KILOMETERS

0 1 2 MILES

MAGNETIC DECLINATION

20°

EXPLANATION

-92

-94

Contour Interval

2 Milligal

III

Anomaly locations

Gravity base at south end of cross-section B-B' at B parallels the axis of the Western Snake River Plain (WSRP). The extensive gravity high in the WSRP is shown in Mabey and others' (1974) gravity survey. Other less important appearing highs are found in and around section 10 at Rocky Point, anomaly IV, and Weiser Hot Springs, anomaly V.

RESIDUAL GRAVITY MAP

The gravity field represented by the Bouguer anomaly map reflects the combination of local and regional gravity anomalies. Anomalies representing local features can be hidden or overshadowed by anomalies representing regional geologic structures. To better understand the local structures, a residual gravity map has been made (Figure 11). A residual gravity map shows only the residue of the gravitational field after the removal of regional gravity effects (Giffin, 1949).

The anomalies present on Figure 11 have been derived from the corrected Bouguer gravity values and exhibit trends and locations similar to those on Figure 10. Anomalies generated by the local structures not previously visible in the flats can now be viewed and interpreted. Three of these anomalies (VI, VII, VIII) are of significant intensity. Anomaly VI is a high in section 17 northeast of Porters Island. When its location is compared to the anomaly locations of the Bouguer anomaly map, it is found to be adjacent to anomally II north of Porters Island. Anomaly VII is a low in the flat. It takes up the southern half of section 22 east of the gravity base station and has no corresponding Bouguer anomaly. The intensity of this low is greater than anomaly VIII. Anomaly VIII surrounds the sand pits in section 18, approximately 3.2 km (2.0 mi) north of Weiser proper, on the northwest-trending boundary between the flat and the highland. It falls almost in the center of the larger corresponding Bouguer anomaly I. The anomaly has bilateral symmetry with a northwest-southeast axis trend. This anomaly, as well as the two previously discussed, is an open, partial anomaly. All three are presently located on the boundary of Figure 11 and lack closure. Without closure, their range, shape, and intensity past the map boundary can only be assumed.

The minor intensity anomalies of interest consist of one low and a series of highs. The low, anomaly IX, surrounds the artesian well in section 9 northwest of Weiser Hot Springs. The highs are of equal intensity in a series from the highland to the flats. The chain starts northwest of Rocky Point, anomaly X_a, drops south to the Weiser Hot Springs, anomaly X_b, and arcs across the flat towards the southwest, anomaly X_c. The last anomaly in this series is adjacent to the major low, anomaly I. Anomalies X_a and X_b correspond with anomalies IV and V, respectively, on Figure 10. Another high, anomaly XI, is found east of Rocky Point in the southwestern portion of section 2.

Figure 11 RESIDUAL GRAVITY WEISER AREA, IDAHO

0 1 2 KILOMETERS

0 1 2 MILES

MAGNETIC DECLINATION

20°

EXPLANATION

-8

-4

CONTOUR INTERVAL

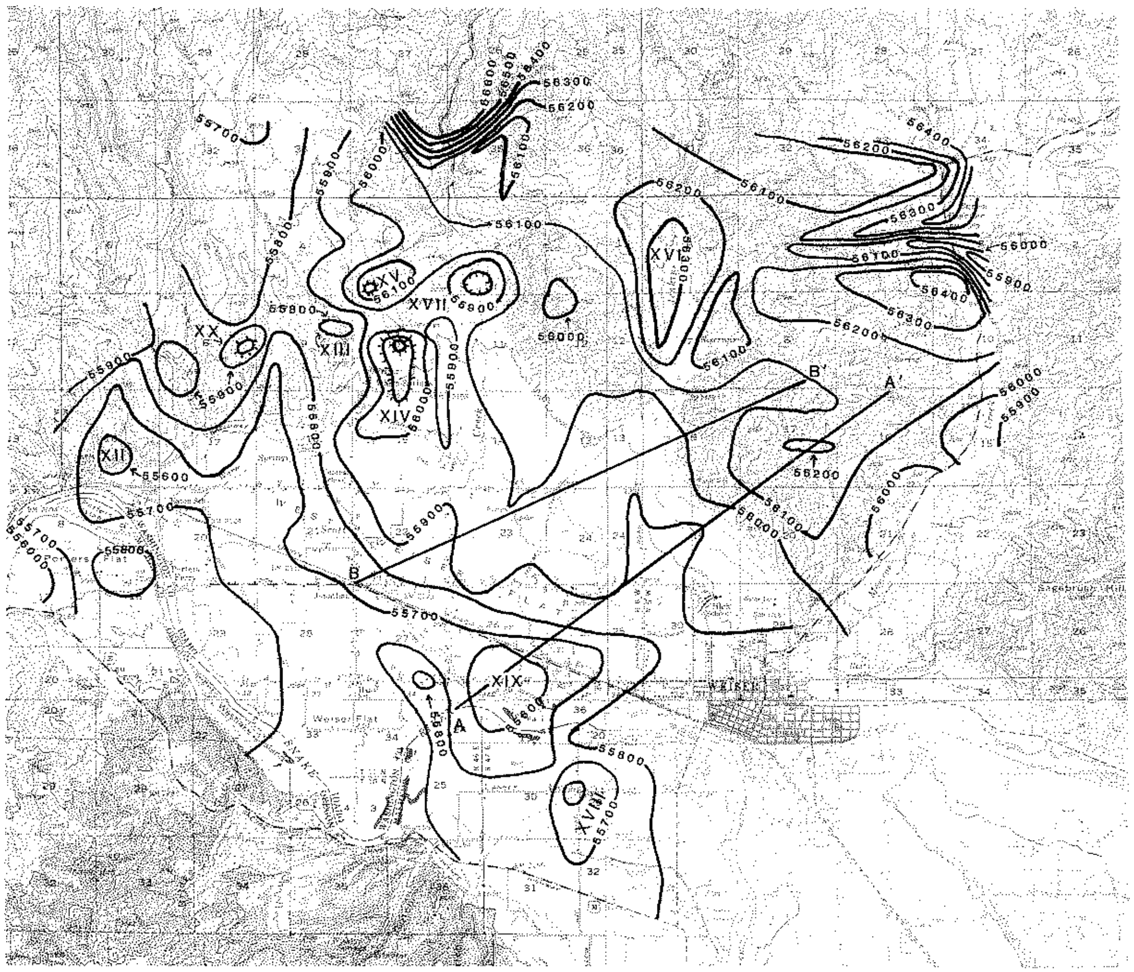
4Mgal/Km²

XI

Anomaly locations

Gravity base at south end
of cross-section B-B' at B

MAGNETIC MAP WEISER AREA, IDAHO



0 1 2 KILOMETERS

0 1 2 MILES

MAGNETIC DECLINATION

20°

EXPLANATION

55600

55700

Contour Interval 100 Gamma

XIII

Anomaly locations

Magnetic base south of gravity base 45.7 meters. Gravity base at south end of cross-section B-B' atB

MAGNETIC MAP

Magnetic data obtained in this study are displayed on Figure 12. Anomalies present on this map are dependent upon the magnetic susceptibility of the local rock. Young and Whitehead (1975) have proposed that the magnetic highs in this region are probably due to strongly magnetic basalts, while the lows are probably due to a thicker underlying section of sedimentary rocks. In comparing this survey to the geologic map, it was determined that the local rock unit with high magnetic susceptibility is the upper Columbia River Basalt. When the Columbia River Basalt is close to the surface, a magnetic high is present. Values on this map (Figure 12) are directly affected by local characteristics of these flows.

Anomalies on Figure 12 are labeled XIII through XX, and are combined with a much larger magnetic trend. This regional trend is a general increase in magnetic values to the northwest, away from the Snake River Plain. In the north to northeastern portion of the study area, the magnetic values are high and extremely variable.

Two types of anomalies are exhibited, those that have some type of corresponding gravity anomaly and those that do not. Six anomalies of concern have been located that have corresponding gravity anomalies. The first, anomaly XII, is a magnetic low north of Porters Island. It is about the same size as anomaly II, which is found in the same location. The second, anomaly XIII, is a magnetic low near the artesian well. This low is similar in size to anomaly IX, the residual gravity low found in the same location. The third and fourth, anomalies XIV and XV, are magnetic highs located near each other, one at Weiser Hot Springs and the other northwest of Rocky Point. Both have corresponding residual gravity and Bouguer anomaly highs: X, Xb and IV, Xa, respectively. The fifth, anomaly XVI, is a magnetic high located in the highland along Jenkins Creek in the western portion of section 6. Its southwest boundary is marked by increasing contours of residual gravity along the boundary of Figure 11. A complete residual anomaly is not visible, however, and this trend is inferred. The sixth, anomaly XVII, is a low found east of Rocky Point, approximately 0.8 km (0.5 mi). This anomaly is unusual in that its corresponding residual gravity, anomaly XI, is a high rather than a low.

Three anomalies are present that do not have corresponding residual or Bouguer anomalies. Two are located near each other forming a northwest trend. Anomaly XVIII is in Oregon at the intersection of Moores Hollow and Annex roads. Anomaly XIX is to the northwest, approximately 2.4 km (1.5 mi) above McRea Island. Anomaly XIX is a broader anomaly as indicated by the spreading out of the contours on its eastern side, however, both anomalies are of approximately the same intensity. The third, anomaly XX, is a minor high in section 8, approximately 2.4 km (1.5 mi) west of Weiser Hot Springs.

DISCUSSION

GEOLOGIC STRUCTURES

Figure 13 is Shah's (1968) geologic map of the Weiser area and shows his mapped geologic structures in solid lines. The structures of importance have been labeled alphabetically and are "a ," "b," "c," and "d." All of these structures follow the northwest trend of the northern fault boundary of the Western Snake River Plain.

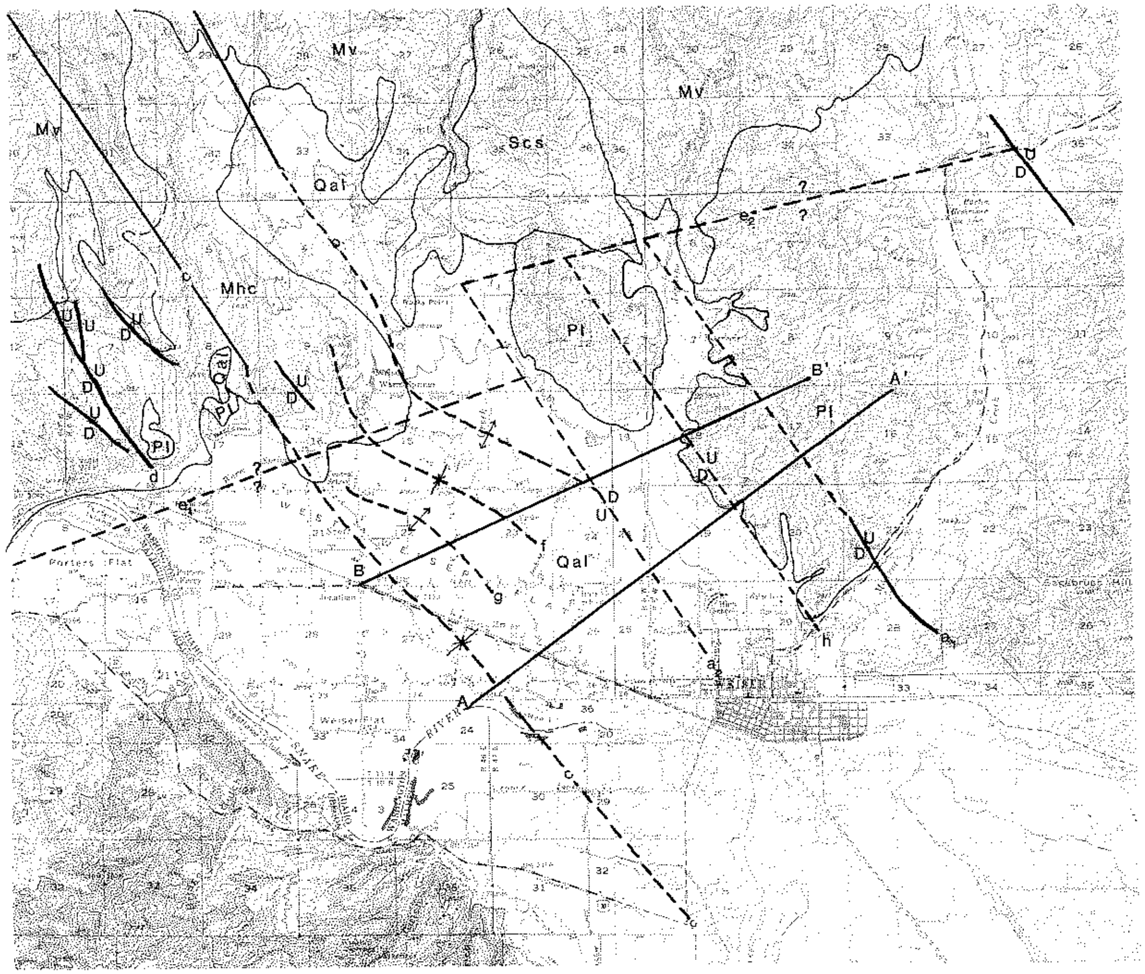
Structure "a " has been mapped as a northwest-striking, high-angle, dip-slip fault dipping to the southwest. It is located northeast of Weiser proper in section 28. The total mapped extent is approximately 3.0 km (1.9 mi).

Structures "b" and "c" appear to be a northwest-trending syncline-anticline couple. The plunge of the folds is towards the plain and they appear to terminate at the Weiser flat/highlands boundary. They are extensive and parallel each other at a distance of approximately 2.5 km (1.5mi).

Structure "d" is a northwest-trending, high-angle, dip-slip fault dipping to the southwest. Its total mapped extent is approximately 3.5 km (2.2 mi). Several other closely related faults are found nearby and form a small zone of fault blocks, down-dropped toward the plain.

RELATIONSHIP OF STRUCTURES TO GEOPHYSICAL ANOMALIES

Gravity and magnetic anomalies reflect the effects of a structure upon their respective fields. Gravity anomalies are found as highs and lows (positive and negative). The gravity lows are due to localized mass (density) deficiencies. These mass deficiencies are assumed to be due to down-dropped blocks in which a greater quantity of less dense sedimentary rocks have been preserved. The gravity highs are the result of local increases in density. Causes for positive density changes range from a decrease in porosity of sedimentary rocks to the presence of igneous emplacements along structural discontinuities. The magnetic highs and lows (positive and negative) are based on the thickness and depth of burial of the magnetically susceptible unit. The highs are interpreted as localized thickening, shallow depth of burial, or solution deposition of magnetically susceptible materials. Lows are interpreted as localized thinning, deep burial, or dissolution of magnetically susceptible material.



GEOLOGIC MAP OF THE WEISER AREA, IDAHO

0 1 2 KILOMETERS

0 1 2 MILES

MAGNETIC DECLINATION

20°

EXPLANATION

——— Structures Mapped by Shah 1966

- - - - - Structures Inferred from this Study

Qal Quaternary Alluvium

MIOCENE PLIOCENE

Pl Idaho Formation

Scs Scott Creek Member

Mhc Hog Creek Member

Mv Volcanics

Geology Modified from Ibrahim Shah 1966

Gravity base at south end of cross-section B-B' atB

Structures "a ," "b," "c," and "d" on Figure 13 are reflected through both gravity and magnetic anomalies that partially or completely agree with predicted anomalies for this type of structure.

Predicted gravity and magnetic anomalies of structure "a ," would be a drop in values southwest of the fault and an increase in values northeast of the fault. The fault would be placed at the halfway point of the anomaly. Anomaly I is the only anomaly that can be interpreted to reflect "a ." The anomaly expresses a low southwest of the fault boundary, however, northwest of the fault boundary the anomaly fades into the background values. Anomaly I is a longer feature than "a ," which may indicate that "a " is much more extensive. The inferred extent is approximately 5.75 km (3.5 mi) further northwest.

Structure "b" is an anticline. The predicted anomalies for this structure would be elongated highs trending along the axis. Two spots along or very near the axis, mapped by Shah (1968), show this trend with anomalies V, Xb, XIV and IV, Xa, XV. These anomalies are slightly offset from the axis which infers that the true axis may also be offset.

Structure "c" is a syncline. The predicted anomalies for this structure would be elongated lows trending along the axis. Anomalies of this direct nature were not present, however, two anomalies, VI and XX, are associated with this structure. Anomaly VI is a high found west of "c's" axis. The eastern flank of anomaly VI parallels the axis and represents the western half of the syncline with its decreasing values toward the axis. Anomaly XX falls on the axis a little further north. It is a small high and is not due to the structure. The anomaly is a localized magnetic high only about 2.75 km (1.7 mi) from the hot springs, indicating that the high may be due to hydrothermal activity in which solution deposition of magnetically susceptible material has taken place.

Structure "d" is a fault with a down-dropped block to the west. The predicted anomalies for this feature would be lows west of the fault and highs east of the fault. Anomalies II, VI, and XII are reflected by this structure. Anomalies II and XII are lows that occur on the western side of the fault displaying the inferred extent of the down-dropped block. On the eastern side of the fault, anomaly VI is found. This is a high that lacks closure, however, it is assumed that the closure of this feature supports structure "d." Thus, it is inferred to reflect the up-thrown block.

INTERPRETATION OF GEOPHYSICAL ANOMALIES

Many of the anomalies located in this study reflected the interpretation of more than one structure. The structures that have been previously discussed all have anomalies that infer extensions or incorporate the effects of other structures.

Structure "a ," a dip-slip fault, is thought to extend much further than mapped due to anomaly I. This anomaly has bilateral symmetry which suggests that its southwestern flank has a mirror structure "a ". Structure "a " is assumed to mirror "a ," such that a graben is represented by anomaly I. When the residual gravity was matched up to the graben structure, it was found that the graben may be broken into two northwest-trending blocks divided by structure "h."

Structure "h" is a fault that parallels "a " and "a " and is placed east of anomaly VIII. Anomaly VIII and the residual gravity values on the left side were lower than the residual gravity values found on the right side of this graben. The difference in values made it necessary to divide the graben into two blocks.

Structure "b," an anticline, has already been inferred to be offset to the east. When the axis reaches the flat, two minor highs, Xc and Xd, are inferred to exhibit the trend of the anticline. The trend of "b" appears to make a more easterly turn in the flat and terminate at "a ."

Structure "c," the syncline, is presumed to extend into the flat following its original trend. Anomalies VII, XVIII, and XIX are lows of considerable relative intensity that fall in line along what would be the inferred trend of the syncline. The intensity of anomaly VII indicates that the axis of this structure may be at a greater depth than either block of the graben. Anomaly XIX, a broad feature, may indicate that the syncline has locally widened.

Between "b" and "c," two other structures are inferred. They are "f" and "g," a syncline and an anticline, respectively. Both follow the trend of anticline "b." Structure "f" begins at anomalies IX and XIII in the highland and dies out past the residual gravity low found at the intersection of sections 14, 15, 22, and 23. Structure "g" parallels "f" to the southwest about 0.8 km (0.5 mi) and extends between two very minor residual gravity highs. These highs are found east of anomaly VII, 1.6 km (1 mi), and northwest of anomaly VII, 1.6 km (1 mi).

Structure "d," the northwest trending fault, is thought to extend approximately 0.5 km (.3 mi) further south in order to separate the high/low combination of anomalies VI/XII.

The southern boundaries of anomalies VI and XII, as well as II, V, Xb, XIV and the northeast topographic boundary, indicate that a northeast structure "e" a possible fault, should be inferred. Structure "e" is shown by McIntyre (1976) on his map.

Structure "e" is the only other local structure present that trends northeast. It is based mainly on topographic alignment. Structure "e" is probably the northern extent of anomaly I. The northern flanks of anomalies XI and XVII also indicate a need to infer this structure.

Anomalies XI and XVII are inferred to represent the northern most extent and termination of "a " into "c" and indicate the intersection of "a " and "c." Anomalies XI and XVII are also of interest because they represent an area of high density and low magnetic susceptibility. Locally, this is uncommon and is the inverse of the normal gravity and magnetic anomaly combinations. This condition may be due to solution-dissolution activity which can alter the density and magnetic character of the local rock.

Anomaly XVI, a magnetic high, corresponds with a set of increasing residual gravity contours. Both anomalies appear to have little in common other than location. The increasing residual gravity contours match up with a predicted anomaly for the inferred structure "a." Anomaly XVI is present on the inferred structure "a "; however, it does not agree with a predicted magnetic anomaly for this structure. The cause for this anomaly is thought to be due to either solution deposition of a magnetically susceptible material along "a " or its close proximity to the exposed flows of the Columbia River Basalt.

Thermal anomalies are compared with the known and inferred structures. Structures "a " through "h" have been overlain on Figure 14 which also contains a thermal gradient map modified from Young and Whitehead (1975, p. 17). The inferred structures "e" and "a " are found to be enhanced partially by bounding a thermal anomaly surrounding Weiser Hot Springs. The cause for this anomaly or warm zone might be the impounding of thermal groundwater by "e" and "a ." The local source for the heated groundwater could be conduits which also supply the hot springs.

PROFILES

Two profile lines (A-A', B-B') are plotted on all of the map plates. Their trend is northeast-southwest. They cross several of the major structures in this area. Line B-B' crosses the syncline-anticline couples "b," "c," "f" and "g" and the large graben structures "a ," "h," "a ." Line A-A crosses only the syncline "c" at its widest point and the graben structures "a ," "h" and "a ." From these lines, gravity, magnetic, and elevation values were obtained and plotted on Figures 15a and b. Figures 15a and b exhibit cross-sectional values of each anomaly crossed in a vertical manner, such that a better interpretation of each anomaly and trend crossed can be attained.

Figure 15a is a graphical representation of all corrected Bouguer, magnetic and elevation values that fall on line A-A'.

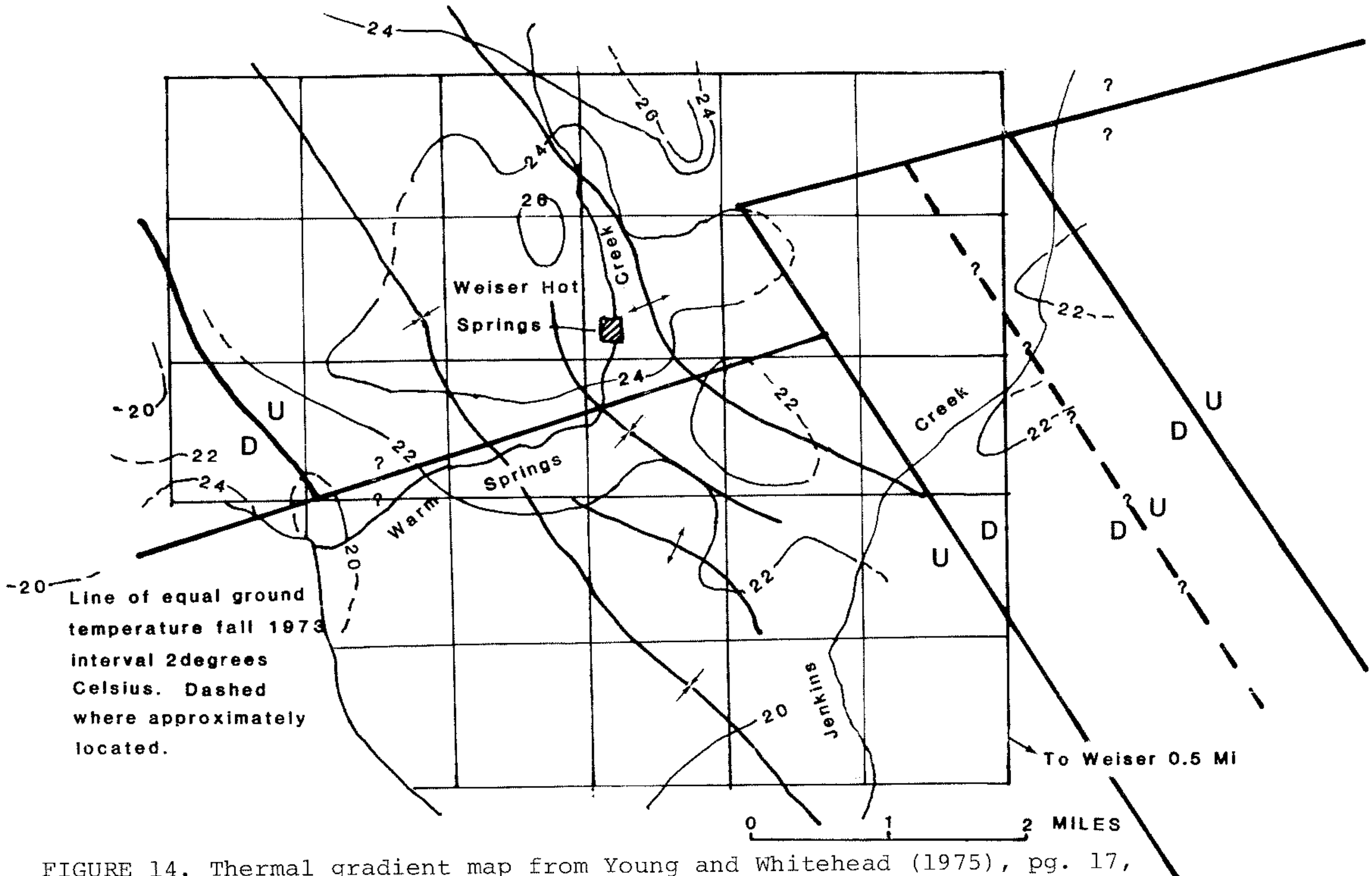


FIGURE 14. Thermal gradient map from Young and Whitehead (1975), pg. 17, figure 7, and the inferred structure map overlain. Warm zones and limitations of the isotherms enhance the structural trends.

The corrected gravity values of this cross section only reflect the low, anomaly I, in which the graben structure was inferred. The effects of other structures are not present on this line because they have been overshadowed by regional gravity effects. The magnetic profile A-A' mirrors the topgraphy and decreases in value towards A. This decrease in value is attributed to the south-southwest dip of the strata. The southwest dip of the strata allows for deeper burial of the magnetically susceptible unit towards the flat (A) and shallower depth towards the highlands (A').

The only feature that shows up on the magnetic profile, other than the regional trend, is syncline "c." This is anomaly XIX located close to A on the profile. The topographic profile reflects only one feature. This feature appears as a low in the profile near A' and may possibly be the northeastern fault boundary of the graben, structure "a ."

Figure 15b is a representation of all the values from the different maps that fall on line B-B'. The gravity profile, like Figure 15a, only reflects the effect of anomaly I and the regional increases in values toward the southwest. Structures that fall on the gravity profile are overshadowed by this regional gravity effect. The magnetic profile reflects only the regional trend of increasing values to the northeast caused by the localized south-southwest dip of the Columbia River Basalts. All other structures are not represented due to a lack of definition. The lack of magnetic definition of these structures may be partially due to a variation in thickness of the Columbia River Basalts. The residual gravity profile exhibits all of the structures crossed. The anticline and synclines "b," "c," "f," and "g" appear on the profile as the first two troughs and mounds away from B. Left of the mound, indicated as anticline "b," are two troughs and one mound. This is the graben. The mound or high in the graben is probably due to an additional fault block formed by structure "h." The topographic profile reflects only what may be the faults of the northern boundary of the graben.

Cross-sectional models for profile lines A-A', B-B' have been made (Figures 16a and b). These models give two dimensional representation of what has been determined from the cross-sectional profiles.

ISOSTACY

The law of isostacy is defined as: "all large land masses on the earth's surface tend to sink or rise so that, given time for adjustment to occur, their masses are hydrostatically supported from below, except where local stresses are acting to upset equilibrium," (Howell, 1959, p. 237). In the region of the Western Snake River Plain, (Hamilton and Myers, 1966, and Mabey, 1976) have determined that the western limb is in approximate

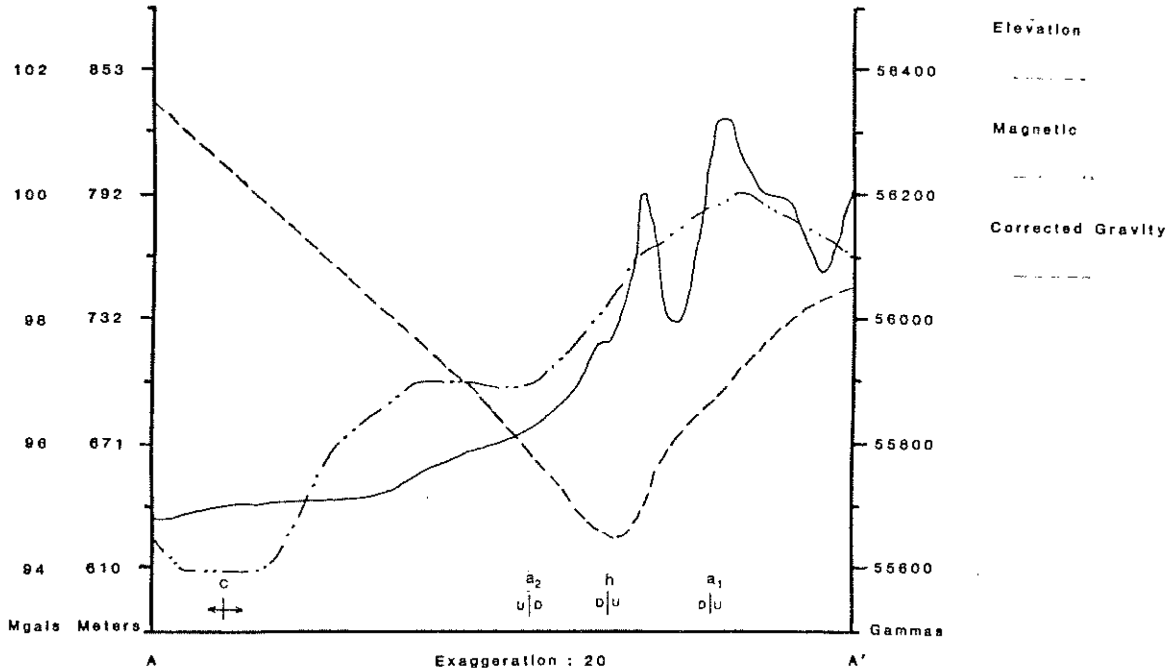


FIGURE 15a.

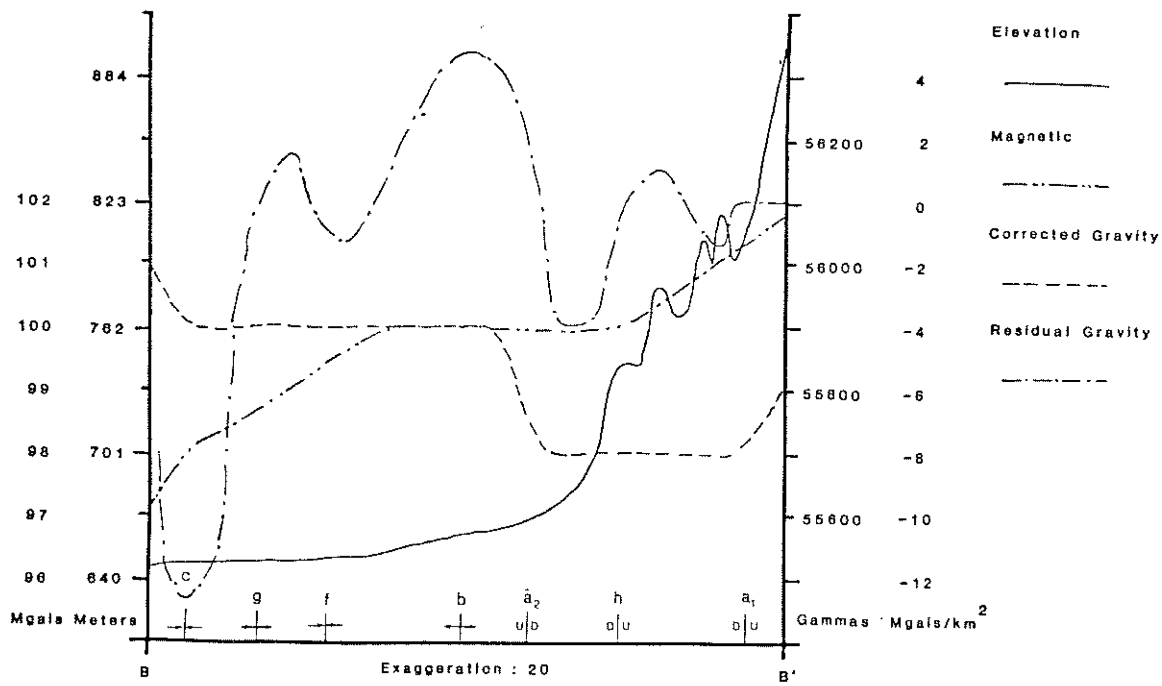
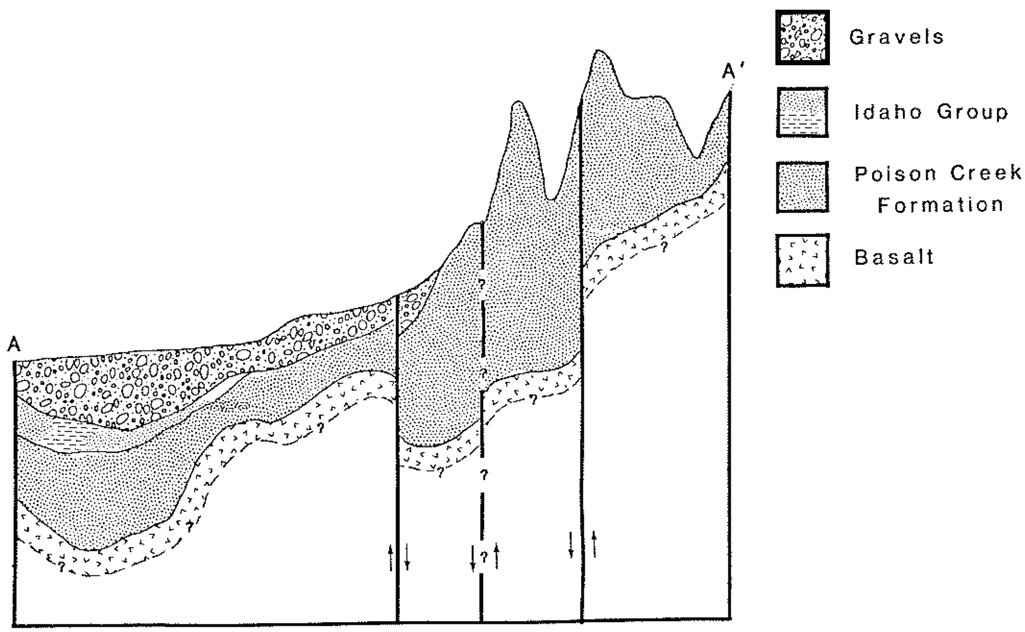


FIGURE 15b.

FIGURE 15. Profile A-A' and B-B'. Structures crossed are indicated at bottom.



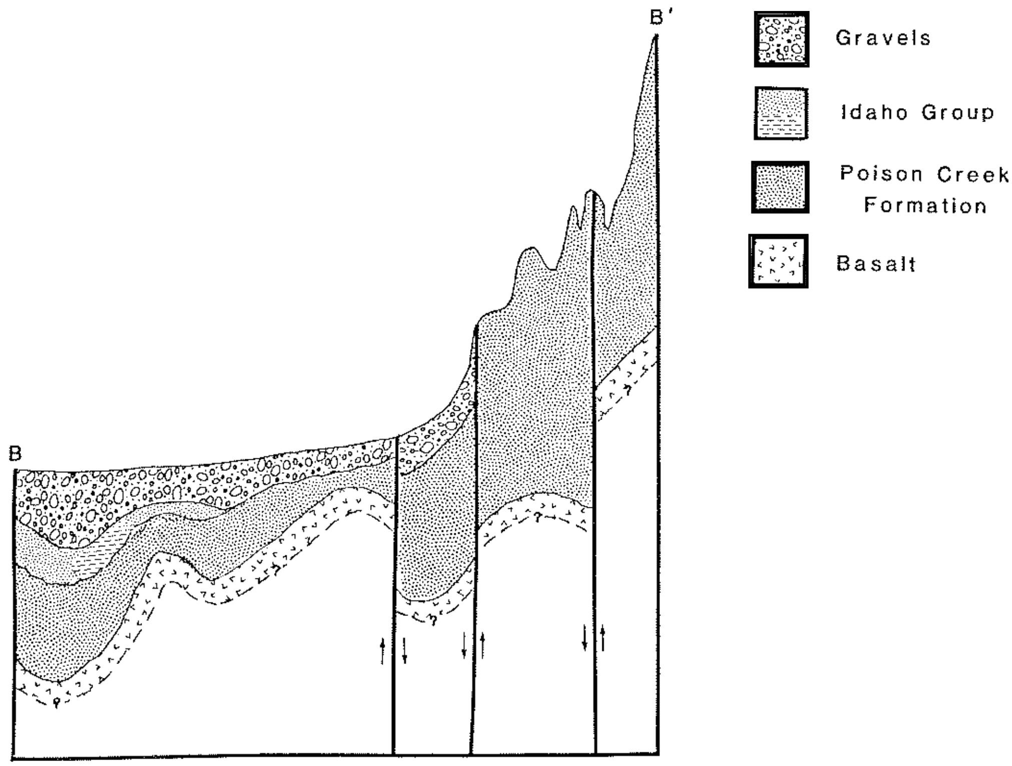


FIGURE 16. Model for profile A-A' and B_B. Not to scale. Inferred break (h) in graben is an extension of the break assumed to exist in profile B-B'. Topography reveals little structural information. Western limb of anticline "b" is present. Thickness of basalt layer variable.

isostatic equilibrium. This indicates that the hydrostatic support has had time to adjust for the thinning of the crust in this region. Hydrostatic equilibrium is obtained by bringing denser material closer to the thinned crust. This denser material, aside from equilibrating the system, also will appear as a gravity high. This gravity high could be the major cause for the regional gravity effects. A portion of the high might exist in the southwest corner of the study area.

CONCLUSIONS AND RECOMMENDATIONS

In the Weiser Hot Springs area, based on geologic data, there is no obvious cause for the hot springs. Therefore, it is assumed that the hydrothermal water is generated elsewhere, and brought to the surface through some minor structure in the anticline. One possible source for this hydrothermal water is from the high-angle fault(s) of the southern boundary of the northwest-trending graben (structure "a "). Groundwater can seep into this fault zone and become superheated at depth. Figure 14 shows that the thermal anomaly around the hot springs is involved with fault structures "a " and "e." Structure "e" may also be the source for the hydrothermal water as inferred from the thermal anomaly. Regardless of the source, the hydrothermal water along with the groundwater is thought to be impounded by structures "a " and "e." This impoundment water backs up the southerly plunging folds. Impounding the water in this manner would allow for the local increase in the ground temperatures surrounding the hot springs. The warm water impoundment could make its way to the surface through some minor structure.

The intensity of the anomalies obtained in this study are weak due to a lack of vertical displacement or lateral density contrast. The lack of intensity only allows for vague structural definition. A geophysical study that would aid in defining the structures present is an electrical resistivity survey. A study of this nature would allow for the location of structures that are impounding groundwater. Structures that impound groundwater appear to be of local importance with regard to hydrothermal activity in this area. Data from a seismic survey of the area would be of great value in further defining structure and depth to various seismically responsive rock units.

The data gathered in this study has made it possible to infer the type of structures present in the Weiser area and more approximately determine extensions thereof. Several of the structures that were geologically mapped not only exist in the highland but also in the flat. Structures "a ," "b," "c," and "d" do exist geophysically and are somewhat modified. Structure "a " has been modified into a graben fault which is thought to be the northern fault boundary of the western Snake River Plain.

Structures "b" and "c" are a syncline-anticline couple bounding a smaller syncline-anticline couple. Structure "d," with the help of "c," has formed a small graben to its west. Another structure which previously was only assumed to exist is "e ." This structure is apparently some type of northeast trending topographic boundary fault with unknown displacement. Structure "e " seems to be linked to the hot springs.

The isotope data gathered, as part of this study, indicates that recharge to the thermal systems were from ancient (Pleistocene) *precipitation which fell in proximity* to the thermal discharges on adjacent slopes or in adjacent mountain ranges. Thermal waters issuing from Weiser, Crane Creek, Cove Creek, and White Licks hot springs have been enriched in ^{18}O indicating that these water have been at higher temperatures than other thermal waters sampled from the study area. There is little or no evidence in the isotope data to indicate that sampled thermal waters are mixtures of thermal and non-thermal waters. Possible exceptions might be water issuing from Stinkey, Warm Springs, and the Glen Hill well.

Included in the report on Figures 5, 13, and 16 are two separate geologic maps and cross sections by different investigators utilizing varied mapping techniques and emphasizing varied aspects for reasons peculiar to each reported project. The differences in rock units described, structural and stratigraphic implications vividly points out the need for further work along the northern margins of the western Snake River Plain, see Mitchell (1981, pp. 134-136). Detailed geologic field mapping, stratigraphic correlation studies and petrographic and geochemistry comparisons of rock units on both margins and in the center of the Plain would aid greatly in better understanding the geology, hydrology and geochemistry of groundwaters in and near the Plain. Geophysical logs of deeper abandoned wells and bore holes obtained within and near the Plain would also aid in this effort. This would greatly expand the ability to locate and evaluate areas which may have potential for geothermal and other groundwater resources in this region. Knowledge gained in such studies would significantly aid in proper resource management and could ultimately have great benefit for the people of the entire state.

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